# REPORT 1035

## ANALYSIS OF MEANS OF IMPROVING THE UNCONTROLLED LATERAL MOTIONS OF PERSONAL AIRPLANES[1]

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### SUMMARY

*A theoretical analysis has been made of means of improving the uncontrolled motions of personal airplanes. The purpose of this investigation was to determine whether such airplanes could be made to fly uncontrolled for an indefinite period of time without getting into dangerous attitudes and for a reasonable period of time (1 to 3 min) without deviating excessively from their original course.*

*The results of this analysis indicated that the uncontrolled motions of a personal airplane could be made safe as regards spiral tendencies and could be greatly improved as regards maintenance of course without resort to an autopilot. The only way to make the uncontrolled motions completely satisfactory as regards continuous maintenance of course, however, is to use a conventional type of autopilot.*

*Theoretical analysis indicated that, although most present-day personal airplanes possess a slight degree of positive spiral stability, they can easily get into dangerous attitudes and deviate excessively from their original course in uncontrolled flight because of out-of-trim moments and insufficient spiral stability. In order to insure even reasonably satisfactory uncontrolled motions, these out-of-trim moments must be almost entirely eliminated by trimming the airplane in flight and by keeping control-system friction low or using some mechanical system to provide positive centering of the controls. Spiral stability can be increased by increasing tail length or increasing the vertical-tail area and dihedral angle simultaneously, or by increasing all of these factors simultaneously, without adversely affecting the flying qualities of the airplane.*


### INTRODUCTION

The problem of making a personal airplane fly uncontrolled for an indefinite period of time without getting into dangerous attitudes and for a reasonable period of time (1 to 3 min) without excessive change in heading has attracted considerable interest. Personal airplanes, when flown by inexperienced pilots or without the proper instruments, may get into dangerous attitudes during periods of blind flying. They may also wander off course while the pilot is busy with maps and navigation problems or is otherwise occupied so that he does not concentrate on flying the airplane. An analysis has been made therefore to determine means of improving the uncontrolled motions of a personal airplane. Although an airplane may possess sufficient stability to insure its return to the original flight attitude following a disturbance such as a gust, it cannot be expected to return to its original heading with respect to the compass without the application of corrective control. If an autopilot is not used to supply this control action, the problem then becomes one of making the airplane safe in uncontrolled flight and reducing the deviation from course to a minimum.

### SYMBOLS

All forces and moments are referred to the stability system of axes which is defined as an orthogonal system having its origin at the center of gravity and the $Z$-axis in the plane of symmetry and perpendicular to the relative wind (positive direction downward), the $X$-axis in the plane of symmetry and perpendicular to the $Z$-axis (positive direction forward), and the $Y$-axis perpendicular to the plane of symmetry (positive direction to right).

| | |
|---|---|
| $S$ | wing area, square feet |
| $S_t$ | vertical tail area, square feet |
| $b$ | wing span, feet |
| $l$ | distance from airplane center of gravity to vertical-tail center of pressure, feet |
| $m$ | mass of airplane, slugs |
| $\rho$ | air density, slugs per cubic foot |
| $V$ | airspeed, feet per second |
| $q$ | dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$ |
| $\beta$ | angle of sideslip, degrees except where otherwise noted |
| $r$ | yawing angular velocity, radians per second |
| $p$ | rolling angular velocity, radians per second |
| $C_L$ | lift coefficient (Lift/$qS$) |
| $C_Y$ | lateral-force coefficient (Lateral force/$qS$) |
| $C_l$ | rolling-moment coefficient (Rolling moment/$qSb$) |
| $C_n$ | yawing-moment coefficient (Yawing moment/$qSb$) |
| $C_{Y_\beta}$ | variation of lateral-force coefficient with angle of sideslip in radians ($\partial C_Y/\partial\beta$) |
| $C_{l_\beta}$ | variation of rolling-moment coefficient with angle of sideslip, per degree except where otherwise noted ($\partial C_l/\partial\beta$) |
| $C_{n_\beta}$ | variation of yawing-moment coefficient with angle of sideslip, per degree except where otherwise noted ($\partial C_n/\partial\beta$) |

[1]Supersedes NACA TN 1997, "Analysis of Means of Improving the Uncontrolled Lateral Motions of Personal Airplanes" by Marion O. McKinney, Jr., 1949.

$C_{l_r}$ variation of rolling-moment coefficient with yawing-angular-velocity factor $\left(\partial C_l/\partial \frac{rb}{2V}\right)$

$C_{n_r}$ variation of yawing-moment coefficient with yawing-angular-velocity factor $\left(\partial C_n/\partial \frac{rb}{2V}\right)$

$C_{l_p}$ variation of rolling-moment coefficient with rolling-angular-velocity factor $\left(\partial C_l/\partial \frac{pb}{2V}\right)$

$C_{n_p}$ variation of yawing-moment coefficient with rolling-angular-velocity factor $\left(\partial C_n/\partial \frac{pb}{2V}\right)$

$C_{L_{\alpha_t}}$ slope of lift curve of vertical tail

$k_X$ radius of gyration about $X$-axis, feet

$k_Z$ radius of gyration about $Z$-axis, feet

$\mu$ relative-density factor $(m/\rho Sb)$

## CALCULATIONS

Two types of calculations were performed in the present investigation: calculations of spiral-stability boundaries and calculations of the motions of several configurations of a hypothetical personal airplane for several disturbances. The characteristics of the basic airplane, which is fairly representative of present-day two-place personal airplanes, are given in references 1 and 2 and were determined by averaging the characteristics of several personal airplanes. The various modified configurations include changes in the dihedral angle, vertical-tail area, and tail length for improving the uncontrolled motions of the conventional personal-airplane configuration. The results of the calculations apply directly only to the hypothetical personal airplane which had a wing loading of 9.25 pounds per square foot and a span of 32 feet. The results can be applied fairly well to specific personal airplanes, however, by dividing the values of time by $\frac{10.5}{b}\sqrt{\frac{W}{S}}$ where $\frac{W}{S}$ and $b$ are the wing loading and span, respectively, of the specific airplane.

The spiral-stability boundaries were calculated by the method presented in reference 3 which states that, for level flight, neutral spiral stability occurs when

$$C_{l_\beta} C_{n_r} = C_{n_\beta} C_{l_r}$$

The values of the stability derivatives $C_{n_r}$, $C_{n_\beta}$, and $C_{l_r}$ used in the boundary calculations are given in table I. The derivative $C_{l_\beta}$ was treated as the dependent variable. The spiral-stability boundaries were calculated with the assumption that the value of $C_{n_\beta}$ was increased by increasing the vertical-tail area so that the value of $-C_{n_r}$ increased as $C_{n_\beta}$ increased.

The rolling and yawing motions of the airplane following various control and gust disturbances were calculated by using the equations of motion presented in reference 3. The applied disturbing moments used in the calculations are given in table II and the stability derivatives used in the motion calculations are presented in table III. The lift coefficient of 0.35 is fairly representative of the lift coefficient of personal airplanes at cruising speed, and the lift coefficient of 1.8 represents the maximum lift coefficient of the airplane with flaps down.

TABLE I.—VALUES OF STABILITY DERIVATIVES USED IN CALCULATIONS OF SPIRAL-STABILITY BOUNDARIES

| $C_{n_\beta}$ | $C_{n_r}$ | |
|---|---|---|
| | Normal tail arm (0.46b) | Long tail arm (0.92b) |
| 0 | −0.039 | −0.078 |
| .001 | −.092 | −.184 |
| .002 | −.145 | −.290 |
| .003 | −.199 | −.398 |
| .004 | −.252 | −.505 |
| .005 | −.305 | −.610 |

| $C_L$ | $C_{l_r}$ | |
|---|---|---|
| | Ailerons fixed | Ailerons free |
| 0.20 | 0.050 | ---------- |
| .35 | .086 | 0.030 |
| .40 | .100 | ---------- |
| .60 | .150 | ---------- |
| .80 | .200 | ---------- |

## RESULTS AND DISCUSSION

A personal airplane may get into a dangerous attitude or deviate excessively from its original course in uncontrolled flight as far as its lateral characteristics are concerned for two reasons: it may be out of trim, or it may be spirally unstable.

TABLE II.—CONDITIONS FOR WHICH MOTIONS WERE CALCULATED

| Type of disturbance | $C_L$ | $C_l$ | $C_n$ |
|---|---|---|---|
| 50° total aileron deflection | 1.80 | 0.040 | −0.008 |
| 50° total aileron deflection | .35 | .060 | −.002 |
| 1° total aileron deflection | .35 | .002 | −.00005 |
| 1° rudder deflection | .35 | 0 | .001 |
| Rolling gust | .35 | .004 | 0 |

TABLE III.—VALUES OF STABILITY DERIVATIVES USED IN CALCULATIONS OF MOTIONS

[$\mu$=3.76, $k_X$=0.150b, $k_Z$=0.183b]

(a) $C_L$=0.35

| Derivative | Configuration | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 1A | 2 | 3 | 4 | 5 | 6 |
| [1]$C_{Y_\beta}$ | −0.274 | −0.274 | −0.274 | −0.510 | −0.274 | −0.274 | −0.510 |
| [1]$C_{l_\beta}$ | −.067 | −.007 | −.137 | −.180 | −.067 | −.137 | −.180 |
| [1]$C_{n_\beta}$ | .064 | .064 | .064 | .172 | .064 | .064 | .172 |
| $C_{l_p}$ | −.425 | −.425 | −.425 | −.425 | −.425 | −.425 | −.425 |
| $C_{n_p}$ | −.022 | −.022 | −.022 | −.022 | −.022 | −.022 | −.022 |
| $C_{l_r}$ | .086 | .030 | .086 | .086 | .086 | .086 | .086 |
| $C_{n_r}$ | −.097 | −.194 | −.097 | −.196 | −.194 | −.194 | −.392 |

(b) $C_L$=1.80

| Derivative | Configuration | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| [1]$C_{Y_\beta}$ | −0.808 | −0.808 | −1.044 | −0.808 | −0.808 | −1.044 |
| [1]$C_{l_\beta}$ | −.130 | −.259 | −.143 | −.130 | −.259 | −.143 |
| [1]$C_{n_\beta}$ | .086 | .086 | .194 | .086 | .086 | .194 |
| $C_{l_p}$ | −.442 | −.442 | −.442 | −.442 | −.442 | −.442 |
| $C_{n_p}$ | −.074 | −.074 | −.074 | −.074 | −.074 | −.074 |
| $C_{l_r}$ | .442 | .442 | .442 | .442 | .442 | .442 |
| $C_{n_r}$ | −.220 | −.220 | −.319 | −.317 | −.317 | −.517 |

[1] $\beta$ in radians.

Several factors are involved in eliminating out-of-trim moments and spiral stability may be increased by several means. The present analysis therefore is divided into two parts for convenience in discussion. The first part treats the uncontrolled motions of a conventional personal airplane and means of improving these motions without changing the geometric configuration of the airplane. The second part treats the uncontrolled motions of various configurations modified geometrically to improve the spiral stability.

## CONVENTIONAL AIRPLANE CONFIGURATION

**Spiral stability.**—An airplane must be spirally stable if it is to fly uncontrolled without diverging from its original attitude. The first step in an analysis of means of improving the uncontrolled lateral motions, therefore, is to determine whether present-day personal airplanes are spirally stable. An indication of whether such airplanes are spirally stable can be obtained from figure 1. This figure shows calculated spiral-stability boundaries for a hypothetical personal airplane at various lift coefficients with fixed controls as functions of the directional-stability parameter $C_{n_\beta}$ and the effective-dihedral parameter $-C_{l_\beta}$. An airplane for which the point on the chart would be on the right side of the boundary is spirally stable; whereas one for which the point would be on the left side of the boundary is spirally unstable. The crosshatched region indicates the position in which points for most present-day personal airplanes would be located on the chart. The lift coefficient corresponding to the cruising speed was determined for several personal airplanes from published performance specifications and was found to be between 0.25 and 0.35. The data presented in figure 1 indicate therefore that most present-day personal airplanes possess a slight degree of positive spiral stability for the cruising-flight condition for which good uncontrolled behavior is most desired.

The significance of a slight degree of positive spiral stability is illustrated by the calculated motion of the hypothetical personal airplane following a disturbance by a rolling gust. The location of the point representing this airplane relative to the spiral-stability boundary is shown in figure 2 (a) where the conventional personal airplane with controls fixed is designated configuration 1. The motion of this airplane following a disturbance by a mild rolling gust $\left(\frac{pb}{2V}=0.01 \text{ for 1 sec}\right)$ is presented in figure 3 where the variations of the angles of bank and heading with time are shown. This figure shows that the gust caused the airplane to bank about 5° and that the airplane slowly returned toward 0° bank. As a result of this bank, the airplane turned considerably off its original course. This motion represents about as poor behavior as could be expected of present-day personal airplanes since the directional stability of the hypothetical airplane ($C_{n_\beta}=0.00115$) is higher than that of most personal airplanes and the cruising lift coefficient of the hypothetical airplane ($C_L=0.35$) is as high as that of any present-day personal airplane. Most personal airplanes, particularly those with relatively high performance, would be expected to return toward 0° bank more rapidly and turn less in response to the same disturbance than configuration 1 since they would probably be more spirally stable than this hypothetical airplane.

The effect on spiral stability of freeing the ailerons is illustrated by the calculations for the hypothetical personal airplane with ailerons free, designated configuration 1A. The following assumptions were made for these calculations: that the value of $-C_{l_\beta}$ was not affected by the freeing of the ailerons, that the airplane had an NACA 4412 airfoil section with Frise ailerons, and that no friction was present in the aileron control system to prevent the ailerons from floating freely. These ailerons have a strong up-floating tendency so that, as the airplane turns with the stick free, the aileron on the faster-moving wing deflects up and the aileron on the slower-moving wing deflects down. This movement of the ailerons tends to roll the airplane out of the turn. In effect, this movement of the ailerons causes the value of $C_{l_r}$ to be lower with stick free than with stick fixed and thereby shifts the spiral-stability boundary as shown for configuration 1A in figure 2 (b). This effect of freeing the ailerons on the motion resulting from a rolling-gust disturbance is illustrated in figure 3 which shows that with the ailerons free (configuration 1A) the airplane returns toward 0° bank more rapidly and does not turn so far off the course as with the ailerons fixed. The airfoil section and the aileron balance assumed for configuration 1A give about as much up-floating tendency as can be expected without resort to some such device as downwardly deflected tabs on the ailerons to provide additional up-floating tendency; therefore, the difference between the motions for configurations 1 and 1A represents the maximum that can be expected from freeing the ailerons unless additional up-floating tendency is provided.

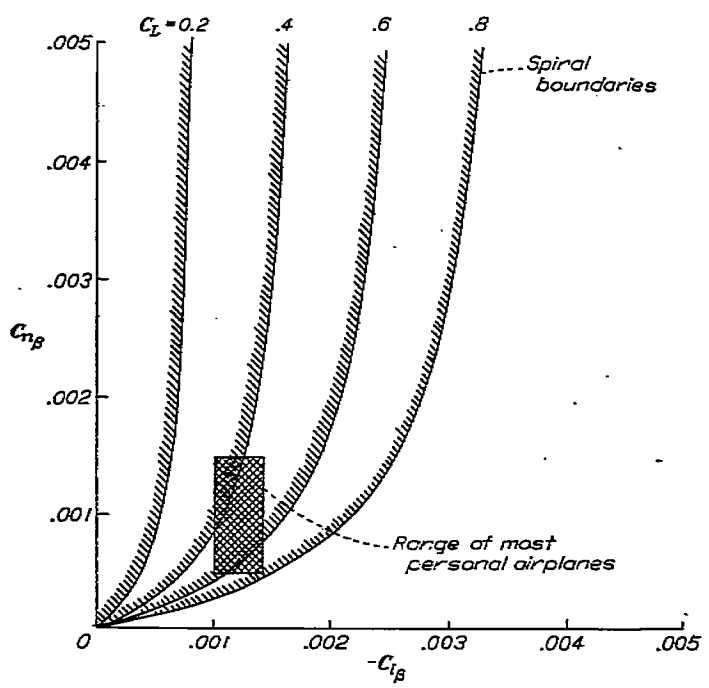
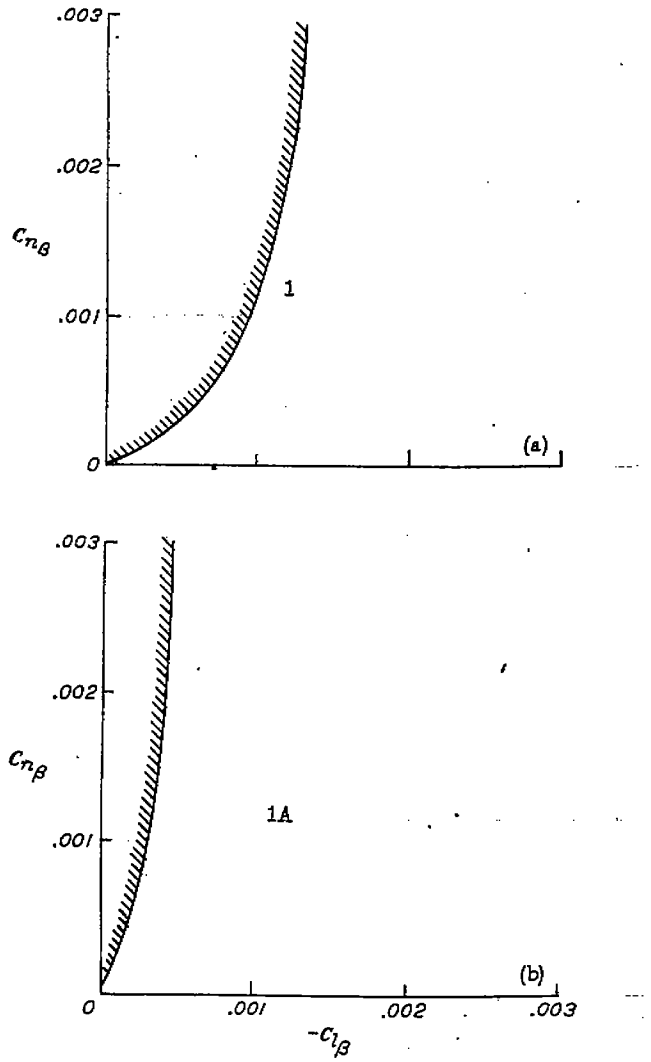



FIGURE 1.—Spiral-stability boundaries for a personal airplane with fixed controls.




(a) Ailerons fixed.
(b) Ailerons free.

FIGURE 2.—Spiral stability of the conventional personal airplane for configurations 1 and 1A.

The effect of freeing the rudder can be ascertained from an analysis of the equation for neutral spiral stability ($C_{l_\beta}C_{n_r}=C_{n_\beta}C_{l_r}$). Freeing the rudder changes the values of $C_{n_\beta}$ and $C_{n_r}$ in approximately the same ratio so that freeing the rudder has almost no effect on spiral stability.

The analysis has shown that most present-day personal airplanes are spirally stable with the controls fixed and will return toward 0° bank following a disturbance although they will have changed heading somewhat and that these airplanes are just as spirally stable or even more spirally stable with controls free than with controls fixed. It is known, however, that in uncontrolled flight most personal airplanes tend to deviate from their original attitude and not return. Since this characteristic, therefore, cannot usually be attributed to spiral instability it must result from out-of-trim moments.

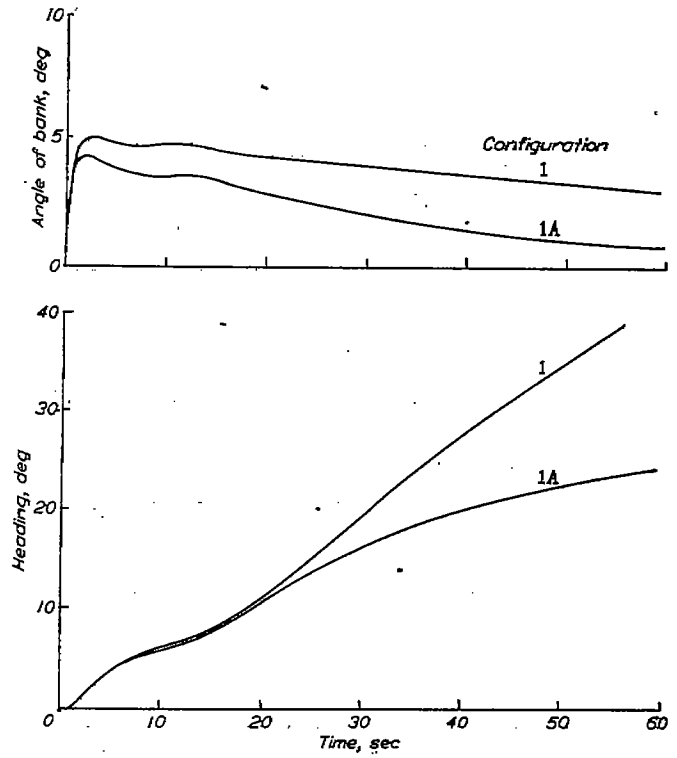



FIGURE 3.—Motions of the conventional personal airplane resulting from a mild gust disturbance (gust strength $\frac{pb}{2V}$=0.01 for 1 sec) for the two configurations shown in figure 2.

**Out-of-trim moments.**—Almost all personal airplanes are out of trim in roll and yaw to a certain extent because of improper rigging, change of trim with power, absence of trim tabs, and control-system friction which prevents proper centering of the controls. As pointed out previously, an airplane has no stability of course. An airplane which is out of trim cannot, therefore, be reasonably expected to fly uncontrolled for an appreciable period of time without considerable change in heading. Trim tabs, or some other means of trimming the airplane in flight should be considered essential, therefore, if the airplane is to fly uncontrolled for a reasonable period of time without excessive change in heading. Control-system friction will tend to hold the controls in the proper position after the pilot has trimmed the airplane with the stick and the rudder pedals, but it will cause considerable trouble that tends to offset this one good characteristic. For example, friction keeps the controls from centering after they are deflected by a gust or other disturbance. Friction also obscures the feel of the controls, a condition which is always objectionable, particularly since the pilot cannot center the controls without the aid of instruments under blind-flying conditions.

The effect of out-of-trim moments on the uncontrolled motions of the hypothetical personal airplane is shown in figures 4 and 5. Figure 4 shows the variation of bank and heading with time when the ailerons are 1° out of trim and figure 5 shows similar motions for the case of 1° out-of-trim

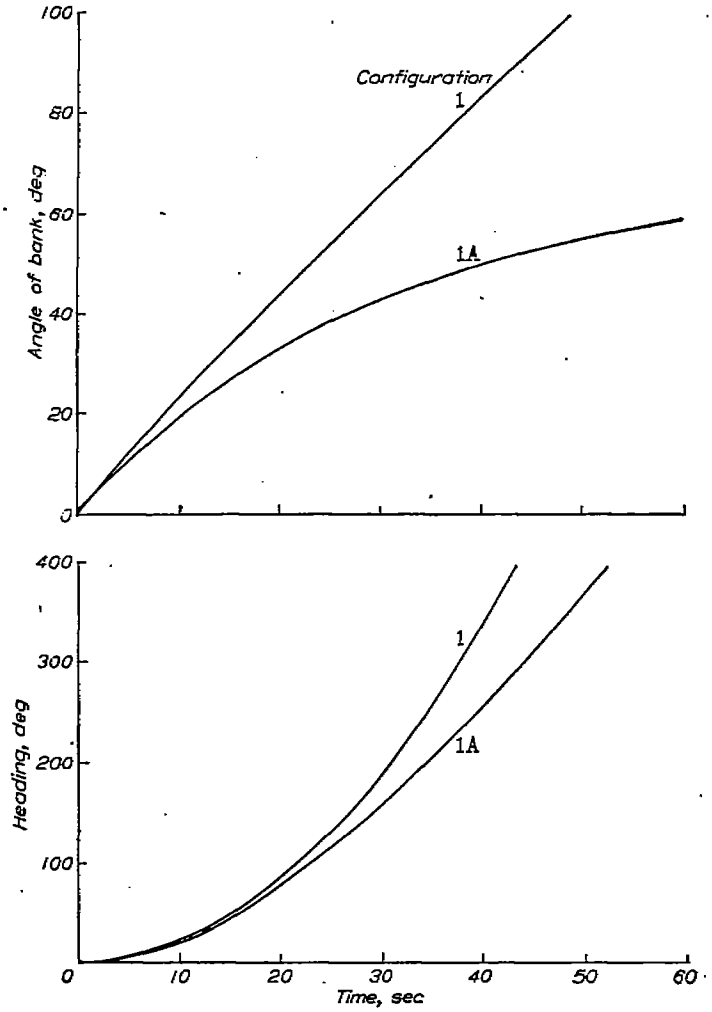



FIGURE 4.—Motions of the conventional personal airplane resulting from 1° out-of-trim aileron deflection for the two configurations shown in figure 2.

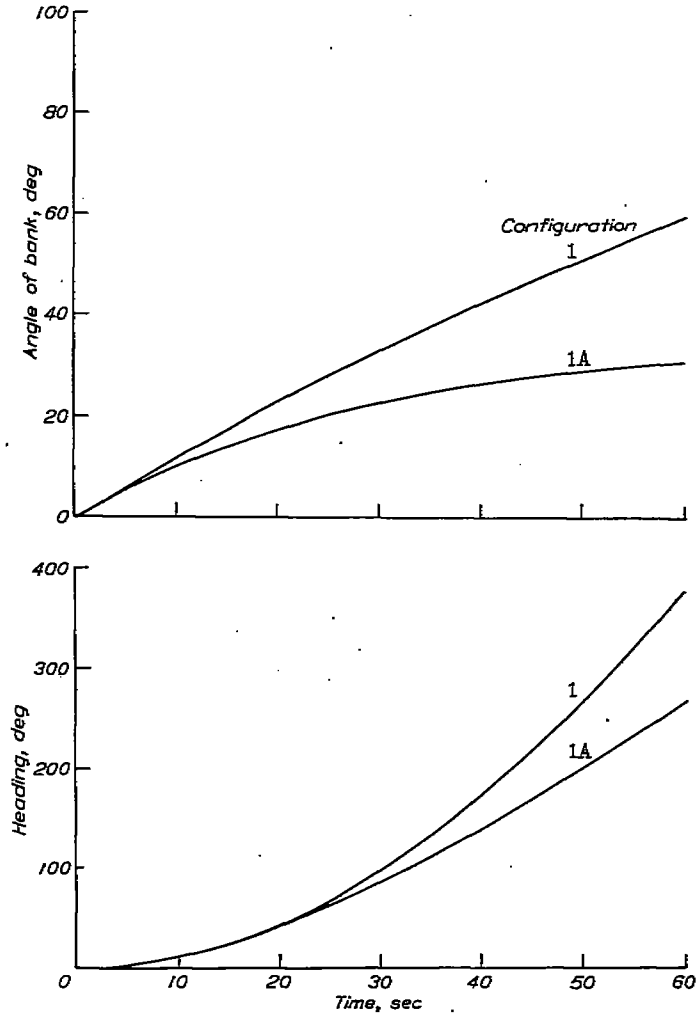
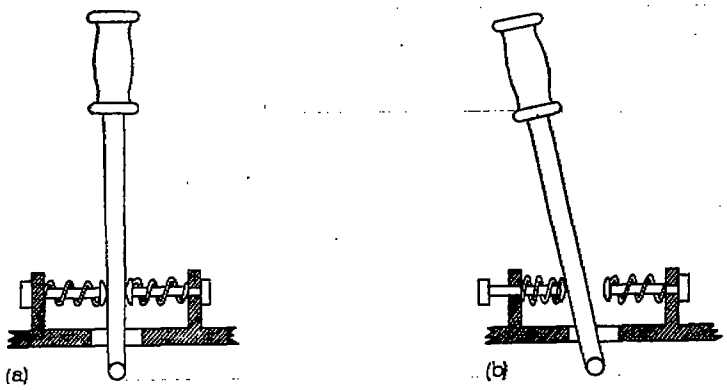



FIGURE 5.—Motions of the conventional personal airplane resulting from 1° out-of-trim rudder deflection for the two configurations shown in figure 2.

rudder deflection. The calculated motions presented in these figures show that, if either the ailerons or rudder are out of trim, the airplane will bank and turn at a fairly rapid rate with no tendency to return to its original attitude as regards either bank or heading. This is true either with the ailerons fixed (configuration 1) where the airplane has slight positive spiral stability or with ailerons free (configuration 1A) where the airplane has considerably more spiral stability. It is apparent from these calculated motions that almost no out-of-trim moments can be tolerated so that, in addition to providing some means of trimming the airplane in flight, the effect of control-system friction in holding the controls deflected and obscuring the feel of the controls must be eliminated.

As pointed out in reference 4, the allowable limits for control-system friction cannot be set at the present time. Vibration of the airplane may relieve, to a certain extent, the effect of friction in holding the controls deflected so that the allowable limits for control friction cannot be determined solely from static considerations of the aerodynamic and frictional hinge moments. Some special flight research work is required to establish an upper limit for the allowable friction as regards proper centering of the ailerons and rudder to prevent an airplane from getting into dangerous attitudes or deviating excessively from its original course in uncontrolled flight.

If keeping the friction forces in the control system low enough is found to be too difficult to be practical for a personal airplane, some mechanical device might be employed that would eliminate the effect of friction without necessitating the elimination of the friction. One such device, the effect of which is being studied experimentally in flight tests at the Langley Aeronautical Laboratory, is illustrated schematically in figure 6. This device consists essentially of preloaded springs that provide positive centering for the controls since at any deflection they provide a restoring force which is greater than the static-friction force in the control system. Since these springs would cause a




(a) Stick centered. (b) Stick deflected.

FIGURE 6.—Schematic diagram of a device for positively centering the controls.

nonlinear control-force gradient through zero deflection which might be annoying to the pilot at times, means for engaging and disengaging the centering device at will might be required. Because of the stretch in the control system, such a device might preferably be installed at the ailerons and rudder rather than on the control stick or rudder pedals as indicated by the sketch. This device could also be used to trim the airplane if the preload in the springs is greater than the control forces required for trim.

If out-of-trim moments are eliminated by trimming the airplane in flight and by eliminating the effect of control-system friction in preventing the controls from centering properly, a conventional personal airplane should be fairly safe as regards the ability to fly uncontrolled for indefinite periods of time without getting into a dangerous attitude and should be fairly satisfactory as regards the ability to fly uncontrolled for reasonable periods of time without excessive deviations from its original course. A considerable improvement in the uncontrolled motions of a personal airplane may, however, be obtained by modifying it to obtain greater spiral stability.

## MODIFIED AIRPLANE CONFIGURATION

Several means are available for modifying a conventional personal airplane so as to increase its spiral stability. These methods are fairly obvious from examination of the relation from reference 3 which shows that an airplane is spirally stable when

$$C_{l_\beta}C_{n_r}>C_{n_\beta}C_{l_r}$$

This expression indicates that spiral stability can be increased by increasing the values of $-C_{l_\beta}$ and $-C_{n_r}$ or by reducing the values of $C_{n_\beta}$ and $C_{l_r}$. The value of $-C_{l_\beta}$ can be increased by increasing the dihedral angle without appreciably affecting the other stability derivatives. The values of $C_{n_\beta}$ and $-C_{n_r}$ are both functions of the vertical-tail size and tail length as shown by the following approximate equations:

$$C_{n_\beta}\approx\frac{S_t}{S}\frac{l}{b}C_{L_{\alpha_t}}$$

and

$$-C_{n_r}\approx 2\frac{S_t}{S}\left(\frac{l}{b}\right)^2 C_{L_{\alpha_t}}$$

where the principal assumption is that the airplane has about zero $C_{n_\beta}$ without a vertical tail. These two equations indicate that $C_{n_\beta}$ and $-C_{n_r}$ can be varied either simultaneously or independently by adjusting the vertical-tail area and tail length. The value of $C_{l_r}$ cannot be changed greatly for the controls-fixed condition by changes to the geometry of the airplane. As previously mentioned, however, $C_{l_r}$ can be varied considerably with the ailerons free by adjusting the aileron floating characteristics.

As pointed out in reference 4, the design conditions for increasing spiral stability often conflict with other factors known to be essential in the attainment of satisfactory flying qualities. When an airplane is modified so as to improve its uncontrolled motions by increasing its spiral stability, the effect of these changes on its flying qualities should be considered. The discussion of the effects of modifications to the conventional personal airplane is presented in two parts: the effect on flying qualities and the effect on the uncontrolled motions.

**Effect of modifications on flying qualities.**—Experience has shown that increasing the dihedral angle of an airplane so as to increase its spiral stability causes its flying qualities to become less satisfactory since the rolling velocity in an aileron roll tends to reverse. With most personal airplanes, however, some increase in dihedral angle can be effected without causing the flying qualities to become unsatisfactory. Experience has also shown that the spiral stability of most personal airplanes should not be increased by reducing the size of the vertical tail (reducing $C_{n_\beta}$) since this change would result in unsatisfactory flying qualities in the form of excessive sideslip in aileron rolls. Analysis of figure 1 indicates that the spiral stability of a personal airplane can be increased by increasing the vertical-tail area and dihedral angle simultaneously so as to maintain the same ratio of $C_{n_\beta}$ to $C_{l_\beta}$ as that of the original airplane. This change can be made without sacrificing controllability. The effect of increasing the tail length and reducing the tail size of a personal airplane so as to increase the damping in yaw without increasing $C_{n_\beta}$ has not been definitely determined. Flight experience with models has indicated, however, that increasing the tail length will not have an adverse effect on controllability.

On the basis of this analysis several modified configurations of the hypothetical conventional personal airplane were chosen for a more detailed analysis of flying qualities and uncontrolled motions. These configurations are indicated by the sketches of figure 7 and by the spiral stability charts of figure 8. Configuration 1 represents the conventional personal airplane which is used as a basis for comparison. Configuration 2 represents an airplane with an increase in dihedral angle of about 6° from configuration 1. Configuration 3 incorporates an increase in dihedral angle of 10° and an increase in vertical-tail area of about 2.5 times that of configuration 1. Configuration 4 represents an airplane having twice the tail length and half the tail area of the conventional personal airplane. Configuration 5 represents

a combination of the high dihedral of configuration 2 and the tail length and tail area of configuration 4. Configuration 6 incorporates a simultaneous increase in dihedral angle of 10° and an increase in vertical-tail area of about 2.5 times that of configuration 4.

The effects of these various modifications on controllability are shown in figure 9 by the calculated rolling motions resulting from 50° total aileron deflection. Figure 9 (a) shows that the controllability in cruising flight is not greatly affected by any of the modifications to the conventional personal-airplane configuration. Figure 9 (b), however, shows that

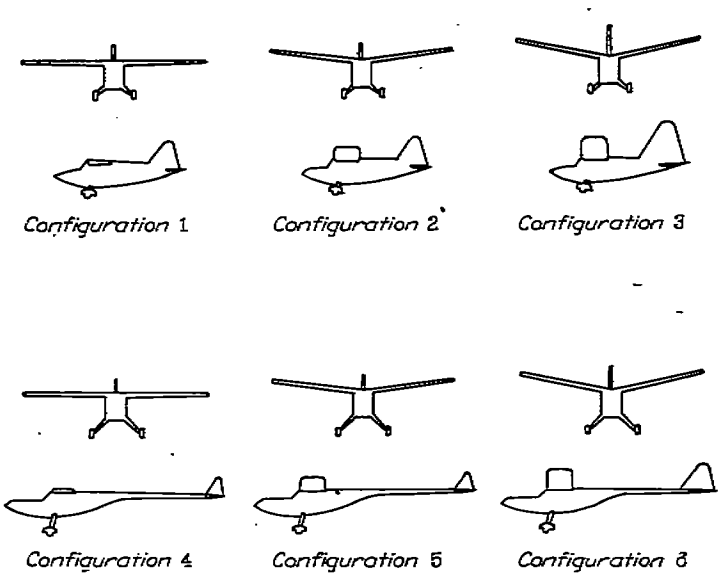
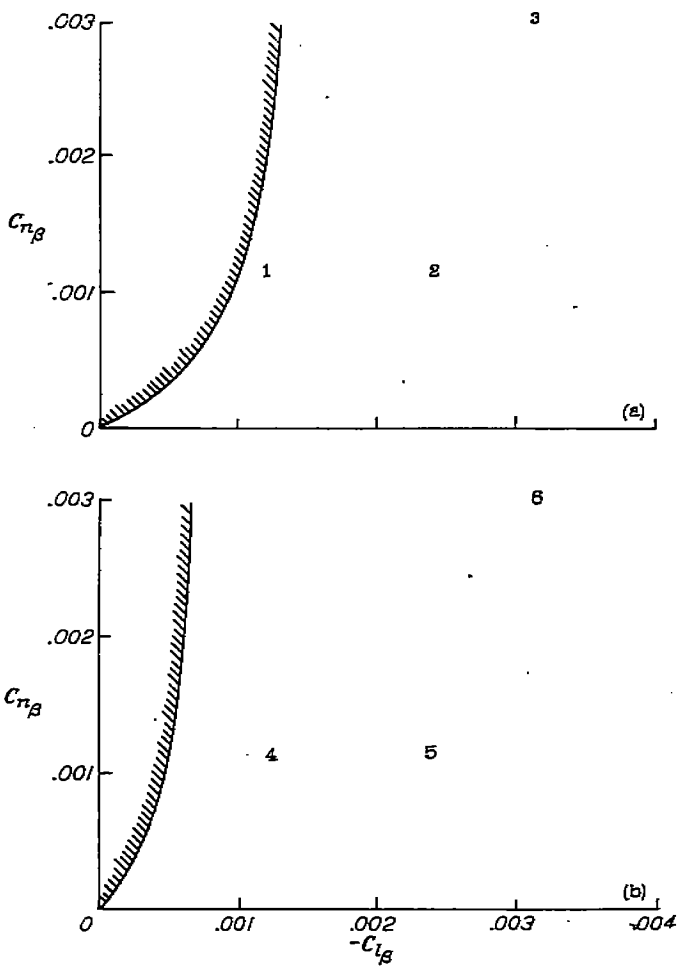
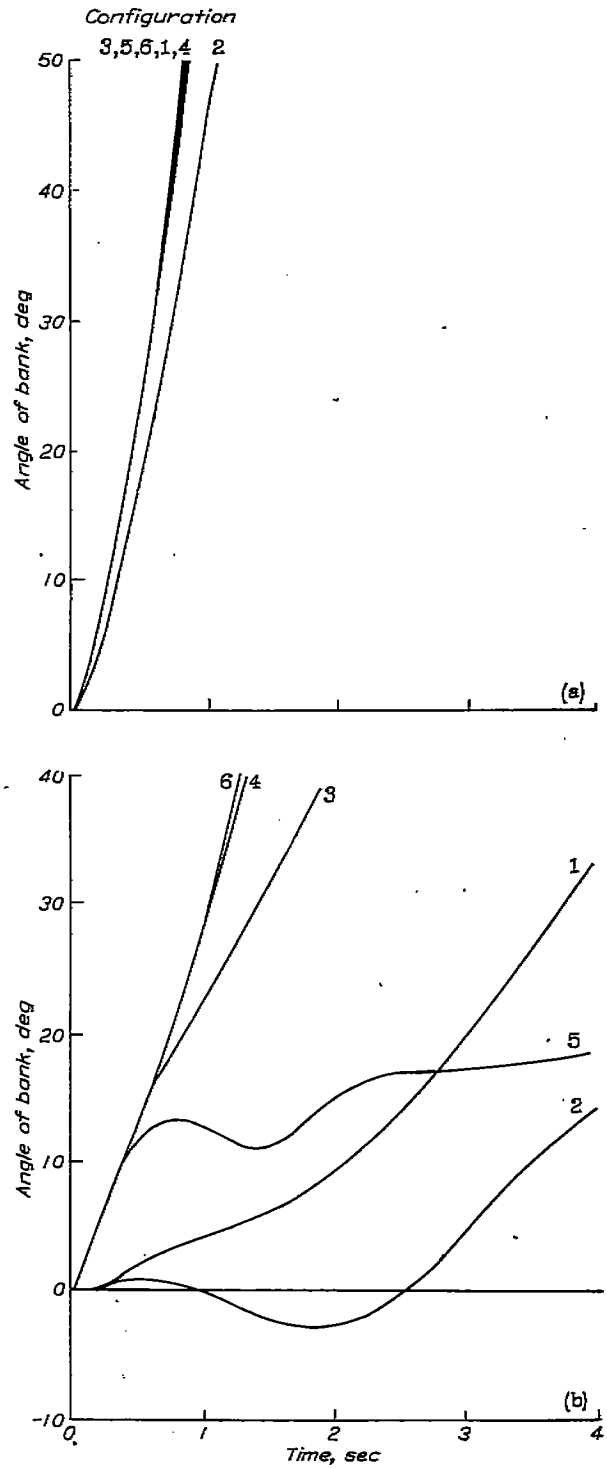



FIGURE 7.—Sketches of the conventional personal airplane (configuration 1) and the modified airplanes (configurations 2 to 6).




(a) $l$=0.46$b$.
(b) $l$=0.92$b$.

FIGURE 8.—Spiral stability of the conventional personal airplane (configuration 1) and the modified airplanes (configurations 2 to 6).




(a) $C_L$=0.35.
(b) $C_L$=1.80.

FIGURE 9.—Rolling motions resulting from 50° total aileron deflection for the six configurations shown in figures 7 and 8.

increasing the dihedral angle (configurations 1 to 2 or 4 to 5) has a pronounced adverse effect on the controllability. The flying qualities for configuration 2 are unsatisfactory since the rolling velocity reverses. Increasing the damping in yaw (configurations 1 to 4 or 2 to 5) or increasing the dihedral angle and vertical-tail area simultaneously (configurations 1 to 3 or 4 to 6) improves the controllability of the airplane at high lift coefficients.

**Effect of modifications on uncontrolled motions.**—The effects of the various modifications on the uncontrolled motions of the personal airplane are shown in figures 10 to 12. These figures show that all the modifications for increasing the spiral stability of the airplane improved its uncontrolled motions. In response to a rolling gust (fig. 10) the modified configurations returned toward 0° bank more rapidly and did not turn as far off course as the original airplane configuration. In response to an out-of-trim aileron or rudder deflection (figs. 11 and 12) the modified configurations did not bank as far or turn off course as fast as the original airplane configuration. These data indicate that, if a personal airplane is modified so as to increase its spiral stability, larger out-of-trim moments can be tolerated than on the conventional configuration.

Increasing the dihedral angle alone (configurations 1 to 2 or 4 to 5) is the least effective method of improving the uncontrolled motions of a personal airplane since the motions resulting from an out-of-trim rudder deflection are about the same with the high dihedral as with the original dihedral. (See figs. 10 to 12.) Since increasing the dihedral alone also causes the controllability to become less satisfactory, this method of increasing the spiral stability does not appear to be very satisfactory. Changing the tail length of personal airplanes very much is probably not very practical because of the greater landing-gear length required when the tail length is increased. The most practical method of increasing the spiral stability of a personal airplane so as to improve its uncontrolled motions appears to be to increase its dihedral angle and vertical-tail area simultaneously (configurations 1 to 3 and 4 to 6), so as to keep the ratio of $C_{n_\beta}$ to $C_{l_\beta}$ about the same, and to use as great a tail length as is practical. As pointed out previously, it is also possible to improve the uncontrolled motions still more for the control-free condition by increasing the upward-floating tendency of the ailerons provided there is no friction to prevent the ailerons from floating freely. This change probably would not affect the controllability of the airplane.

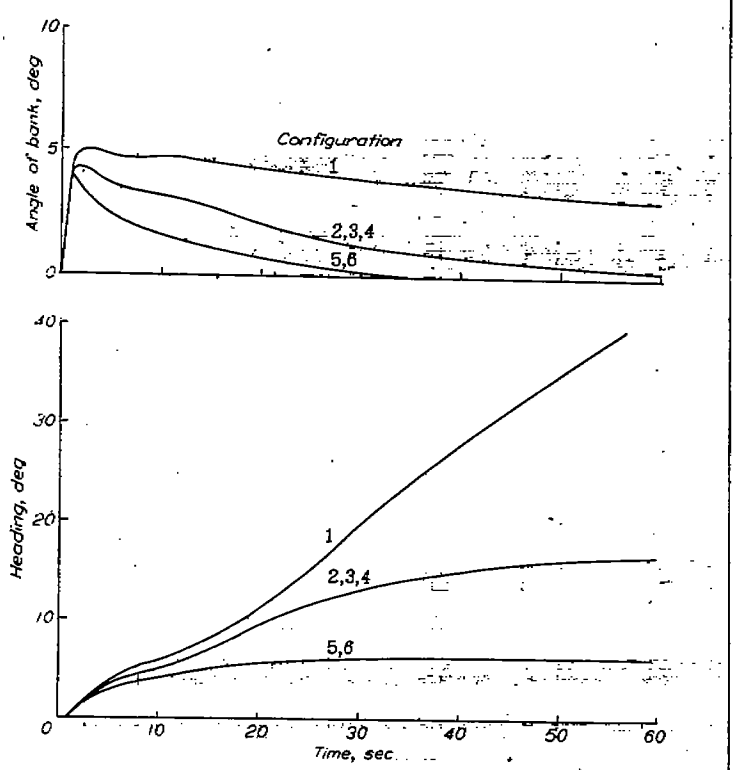



FIGURE 10.—Motions resulting from a mild gust disturbance (gust strength $\frac{pb}{2V}$=0.01 for 1 sec) for the six configurations shown in figures 7 and 8.

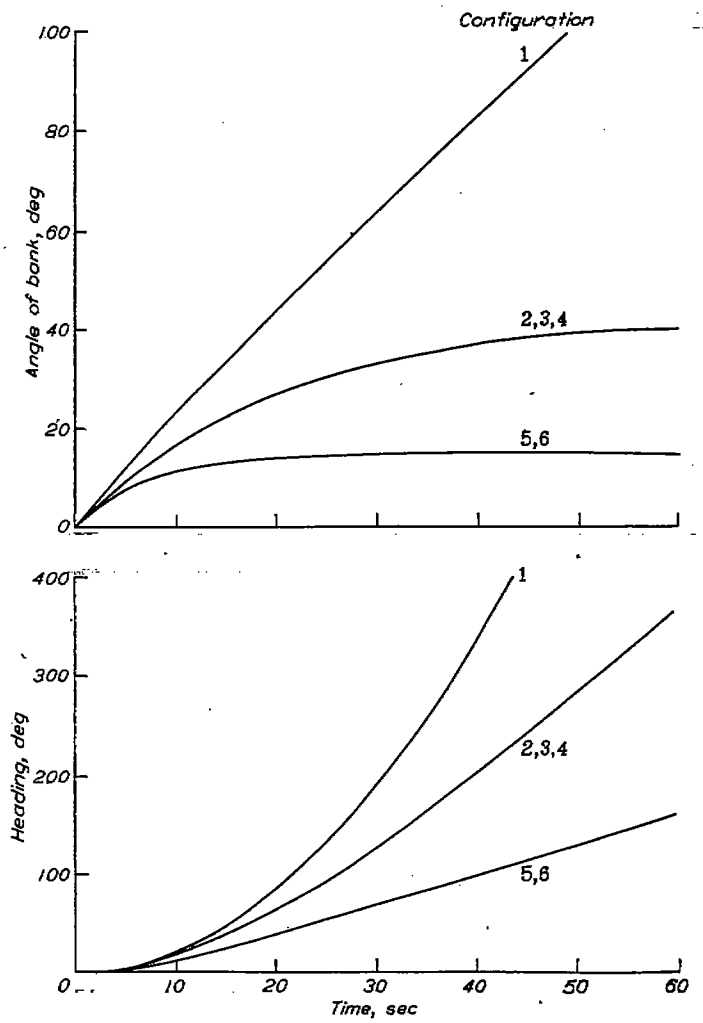



FIGURE 11.—Motions resulting from 1° out-of-trim aileron deflection for the six configurations shown in figures 7 and 8.

### GENERAL CONSIDERATIONS REGARDING MAINTENANCE OF COURSE

As pointed out previously, an airplane has no stability of course and consequently cannot be expected to return to its original course after a disturbance unless a conventional type of autopilot is used. This fact is illustrated in figures 3 and 10 where it is shown that there is a change of heading after a gust disturbance even for very spirally stable configurations. Continuous maintenance of course cannot, therefore, be obtained without an autopilot. Fairly good maintenance of course over a reasonably long period of time should be possible, however, without an autopilot if the airplane is spirally stable and stays in trim. From the theory of random motion, the deviation from course due to random gust disturbances would be expected to average out to no deviation over an infinite period of time. For any finite period of time, however, the deviations from course due to random gusts would tend to add up to no deviation but would not be expected to add up to exactly zero deviation. Because of this tendency for the deviations caused by random gusts to cancel out, the deviation from course over a easonably long period of time would be expected to be fairly small.

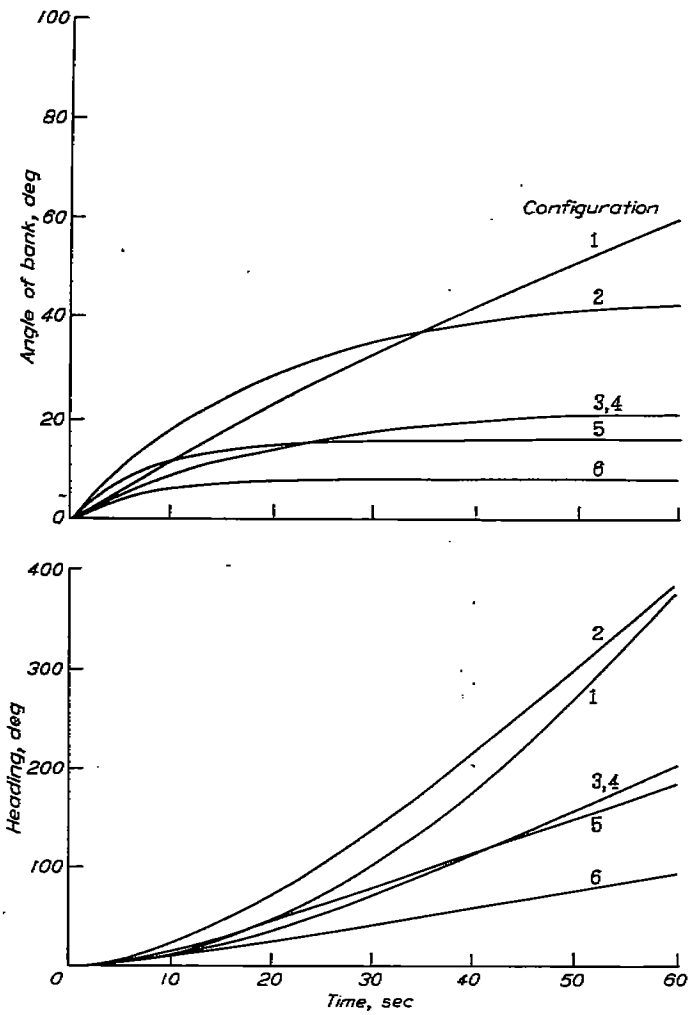



FIGURE 12.—Motions resulting from 1° out-of-trim rudder deflection for the six configurations shown in figures 7 and 8.

## CONCLUSIONS

An analysis of the uncontrolled motions of personal airplanes has shown that a personal airplane can be made safe as regards spiral tendencies and its uncontrolled motions as regards maintenance of course can be greatly improved without resort to an autopilot. The only way to make the uncontrolled motions completely satisfactory as regards continuous maintenance of course, however, is to use a conventional type of autopilot.

Theoretical analysis has indicated that most present-day personal airplanes possess a slight degree of positive spiral stability but can easily get into dangerous attitudes and deviate excessively from their original heading in uncontrolled flight because of out-of-trim moments and insufficient spiral stability. In order to insure even reasonably satisfactory uncontrolled motions, these out-of-trim moments must be eliminated or at least reduced to very small magnitudes. Some means of trimming the airplane in flight is necessary, therefore, and the effect of control-system friction in preventing proper centering of the controls by the pilot or by the aerodynamic forces must be almost entirely eliminated by having very low friction or by having some mechanical device that will provide positive centering of the controls. Increasing the spiral stability will also improve the uncontrolled motions of personal airplanes. An increase in spiral stability for personal airplanes can be obtained by increasing tail length or increasing the vertical-tail area and dihedral angle simultaneously, or by increasing all of these factors simultaneously, without adversely affecting the flying qualities of the airplane.

LANGLEY AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *June 22, 1949.*

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