NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT 1092

FLIGHT INVESTIGATION OF THE EFFECT OF CONTROL CENTERING SPRINGS ON THE APPARENT SPIRAL STABILITY OF A PERSONAL-OWNER AIRPLANE

By JOHN P. CAMPBELL, PAUL A. HUNTER, DONALD E. HEWES,
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1952

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National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW., Washington 25, D. C.

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Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

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By John P. Campbell, Paul A. Hunter, Donald E. Hewes, and James B. Whitten

SUMMARY

A flight investigation has been conducted on a typical high-wing personal-owner airplane to determine the effect of control centering springs on apparent spiral stability. Apparent spiral stability is the term used herein to described the spiraling tendencies of an airplane in uncontrolled flight as affected both by the true spiral stability of the perfectly trimmed airplane and by out-of-trim control settings. Centering springs were used in both the aileron and rudder control systems to provide both a positive centering action and a means of trimming the airplane. The springs were preloaded so that when they were moved through neutral they produced a nonlinear force gradient sufficient to overcome the friction in the control system and to produce the forces required to hold the control surface at the proper setting for trim. The aileron and rudder control surfaces did not have trim tabs that could be adjusted in flight.

Although the airplane was shown to be spirally stable at airspeeds above approximately 90 miles per hour with the controls held in the trim position, it appeared to be spirally unstable with controls free and with the centering springs disengaged because of the moments produced by out-of-trim control positions. After an abrupt rudder kick and release with the centering springs disengaged, the airplane appeared to diverge in the direction of the rudder kick because friction prevented the rudder from centering. With the centering springs engaged to hold the controls in the exact trim positions, however, the airplane quickly returned to straight and level flight after a rudder kick and would fly "hands off" for indefinite periods of time without getting into a dangerous attitude, at least, in the smooth or moderately rough air in which all the tests were made. An indication that the airplane might not fly satisfactorily "hands off" in very rough air, however, was obtained from results of attempted recoveries from large angles of bank with the elevator free. These results showed that, because of the effect of airspeed on lateral and directional trim, satisfactory recoveries could be obtained only by keeping the airspeed essentially constant. These results also indicate that in order to get completely satisfactory results with control centering springs it will probably be necessary to minimize lateral-directional trim changes due to changes in airspeed, power, and fuel loading and to increase the true spiral stability of the airplane. The effect of the centering springs on the aileron control-force characteristics was not considered objectionable by the pilots since the breakout force (friction plus spring preload) was relatively small (approx. 3.5-lb wheel force). The rudder force characteristics, however, were considered objectionable because the excessive friction in the rudder control system required the use of a large preload and consequently resulted in a large breakout force (approx. 22-lb pedal force).

INTRODUCTION

During the last few years there has been an increasing amount of interest in improving the spiral stability of personal-owner aircraft. One goal has been to have the airplane fly "hands off" for reasonable periods of time without large changes in heading so that the pilot is not required to control the airplane continually and can devote adequate time to navigation problems. Another goal has been to have the airplane fly safely "hands off" for indefinite periods so that when the pilot is caught in "blind-flying" conditions, he can safely release the controls and will not have to depend on his sense of orientation to keep the airplane in a safe attitude. The unreliability of the pilot's sense of orientation is demonstrated very clearly in the flight test results reported in reference 1.

A recent study by the National Advisory Committee for Aeronautics to determine how the spiral stability of personal-owner airplanes can be improved (reference 2) has made clearer a point which has been recognized for some time—that many light airplanes (particularly high-wing designs) are inherently spirally stable in the cruising condition even though they do seem to show unstable spiral tendencies in flight. The two reasons for this apparent spiral instability are: First, a lack of means of trimming the airplane in flight makes it impossible for many light airplanes to ever be perfectly trimmed for straight wing-level flight; and, second, whether or not the airplane has means for trimming, the friction usually present in most light-airplane control systems makes maintaining the same trimmed condition indefinitely difficult or even impossible because friction prevents the control surface from centering after a deflection.

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[1] Supersedes NACA TN 2413, "Flight Investigation of the Effect of Control Centering Springs on the Apparent Spiral Stability of a Personal-Owner Airplane" by John P. Campbell, Paul A. Hunter, Donald E. Hewes, and James B. Whitten, 1951.

Therefore, if an inherently spirally stable light airplane (most high-wing designs and probably low-wing designs with adequate wing dihedral) is provided with means for trimming the ailerons and rudder and if the friction in the control system is reduced to an extremely low value, the airplane might fly itself satisfactorily. One of the greatest difficulties appears to be the reduction of the control-system friction to a negligible amount, because even a small amount of friction will cause trouble. One method suggested in reference 2 for obviating the requirement for negligible friction is to use preloaded control centering springs that have a nonlinear force gradient through neutral deflection and, thereby, provide a positive centering action despite friction in the control system. (See fig. 1.) Centering springs of this type also afford a simple means of trimming the airplane since enough additional preload can be provided to produce the forces required to hold the surface at the proper setting for trim. If the additional preload required for trimming is large, however, the control forces are likely to be objectionably high.

In order to determine the effect on apparent spiral stability of a centering device of this type, a flight investigation has been made with a typical high-wing personal-owner airplane equipped with centering springs in both the aileron and rudder control systems. Flight tests were made with the aileron and rudder springs both engaged, with each spring engaged singly, and with both springs disengaged. Records were obtained of the uncontrolled lateral motions of the airplane starting from straight and level flight and from turns and also following abrupt rudder kicks. Most of the flights were made at speeds from 140 to 150 miles per hour, but a few flights were made at 120 and 90 miles per hour. The theoretical spiral stability of the airplane was calculated for correlation with the flight test results.

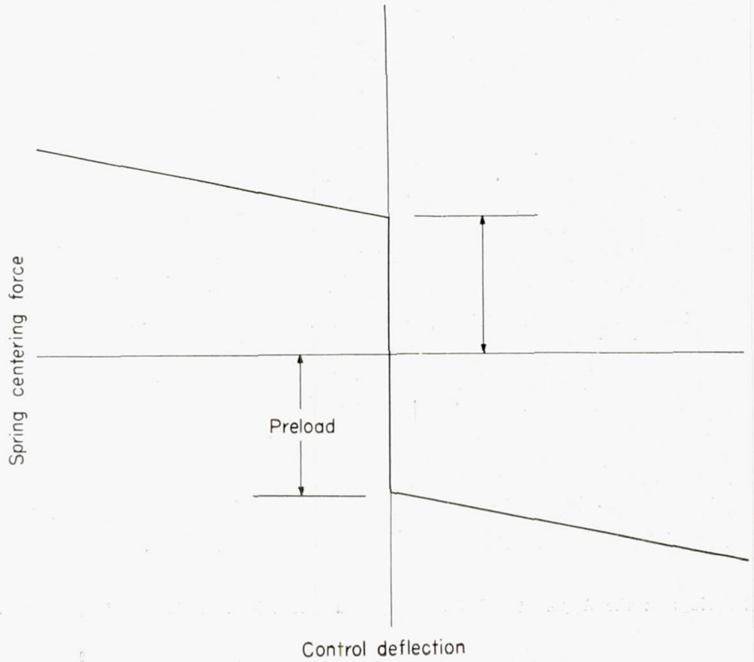


FIGURE 1.—Variation of spring centering force with control deflection for a positive-action control centering spring. (Spring preload must be greater than static friction in control system.)

SYMBOLS

All force and moment coefficients are referred to the stability system of axes with the origin at the center of gravity of the airplane.

b	wing span, feet
S	wing area, square feet
ρ	mass density of air, slugs per cubic foot
V	indicated airspeed, miles per hour unless otherwise noted
q	dynamic pressure, pounds per square foot $\left(\frac{\rho}{2}V^2;\ V \text{ expressed in ft/sec}\right)$
δ	deflection of control surface, degrees
α	angle of attack of longitudinal reference axis, degrees
η	angle of attack of principal longitudinal axis of inertia, degrees
γ	flight-path angle, degrees
β	angle of sideslip, positive in sideslip to right, radians
ϕ	angle of bank relative to horizon, positive to right, degrees
ψ	angle of heading relative to initial heading at beginning of flight record, positive to right, degrees
p	rolling angular velocity, radians per second
r	yawing 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)

$$C_{Y_\beta}=\frac{\partial C_Y}{\partial \beta}$$

$$C_{l_\beta}=\frac{\partial C_l}{\partial \beta}$$

$$C_{n_\beta}=\frac{\partial C_n}{\partial \beta}$$

$$C_{Y_p}=\frac{\partial C_Y}{\partial \frac{p}{2V}}$$

$$C_{l_p}=\frac{\partial C_l}{\partial \frac{pb}{2V}}$$

$$C_{n_p}=\frac{\partial C_n}{\partial \frac{pb}{2V}}$$

$$C_{Y_r}=\frac{\partial C_Y}{\partial \frac{rb}{2V}}$$

$$C_{l_r}=\frac{\partial C_l}{\partial \frac{rb}{2V}}$$

$$C_{n_r}=\frac{\partial C_n}{\partial \frac{rb}{2V}}$$

m	mass, slugs
μ_b	relative density coefficient based on wing span $(m/\rho Sb)$
k_{X_0}	radius of gyration about principal longitudinal axis, feet
k_{Z_0}	radius of gyration about principal vertical axis, feet
K_X	nondimensional radius of gyration about longitudinal stability axis $\left(\sqrt{\frac{{k_{X_0}}^2}{b^2}\cos^2\eta+\frac{{k_{Z_0}}^2}{b^2}\sin^2\eta}\right)$
K_Z	nondimensional radius of gyration about vertical stability axis $\left(\sqrt{\frac{{k_{Z_0}}^2}{b^2}\cos^2\eta+\frac{{k_{X_0}}^2}{b^2}\sin^2\eta}\right)$
K_{XZ}	nondimensional product-of-inertia parameter $\left(\left(\frac{{k_{Z_0}}^2}{b^2}-\frac{{k_{X_0}}^2}{b^2}\right)\cos\eta\sin\eta\right)$
$T_{1/2}$	time for spiral mode to damp to one-half amplitude, seconds

Subscripts:

a	aileron
r	rudder
e	elevator

APPARATUS

AIRPLANE

Flight tests were conducted on the personal-owner airplane shown in the photograph, figure 2, and in the three-view drawing, figure 3. Table I presents dimensional data for the airplane. The aileron control system is the cable type with needle-bearing pulleys for low system friction. The rudder control system consists of a combination of cables and push-pull rods. The aileron and rudder control surfaces did not have trim tabs that could be adjusted in flight.

The forces in the aileron and rudder control systems produced by the combined effects of friction and the centering devices are shown in figure 4. This figure consists of a plot of the variation in pedal and wheel forces with control-surface deflection with the centering springs engaged. Since the values presented were obtained by averaging several calibrations that were not in very good agreement, they are considered only approximate values. The friction force was assumed to be one-half the difference (near neutral position) between the forces measured with the control moving away from neutral and toward neutral. The spring preload was obtained by subtracting the friction force from the breakout force (the force required to deflect the control from the neutral position).

INSTRUMENTATION

Standard NACA instrumentation was provided to measure airspeed, control positions, angle of bank, and change in heading. The change in heading was obtained from a standard directional gyroscope which was modified to permit recording of heading on film. Airspeed as used in this report is indicated airspeed as obtained by measuring pressures from a total-pressure tube and a swivel static tube mounted on a ½-chord boom ahead of the wing leading edge. Elevator angles were measured with respect to the thrust axis and rudder angles were measured with respect to the fin.

CENTERING DEVICES

A sketch showing the location of the centering devices relative to the control system of the airplane is shown in figure 5. This arrangement was designed so that the installation of the centering springs could be made with a minimum of alterations to the existing structure and control system. The aileron centering device was located in the

FIGURE 2.—Test airplane.

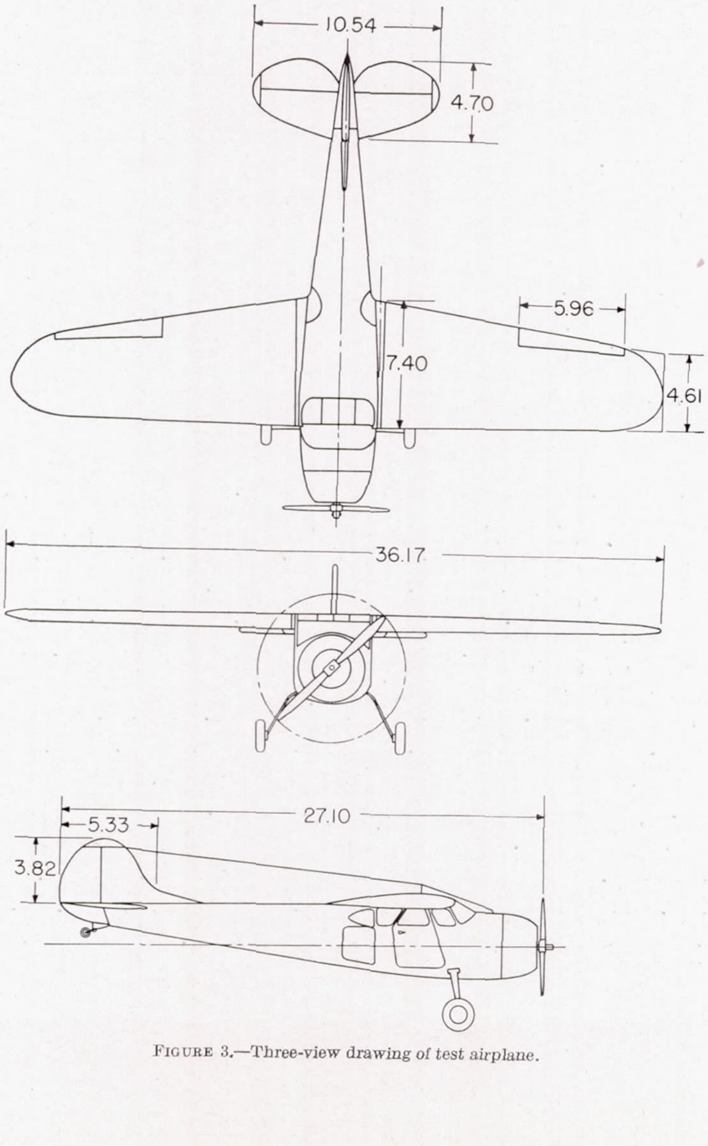


FIGURE 3.—Three-view drawing of test airplane.

TABLE I.—DIMENSIONAL DATA FOR TEST AIRPLANE

Design gross weight, lb	3,350
Horsepower (at 2200 rpm)	240
Propeller diameter, ft	7.75
Over-all length, ft	27.10
Wing:	
Area (including fuselage), sq ft	218.13
Span, ft	36.17
Dihedral, deg	0.7
Aspect ratio	6.00
Taper ratio	0.62
Mean aerodynamic chord, ft	6.30
Incidence, deg	1.0
Washout, deg	1.5
Airfoil section	NACA 2412
Flap area, sq ft	8.68
Aileron area, sq ft	12.32
Flap deflection, deg	
Down	45
Aileron deflection, deg	
Up	25
Down	25
Horizontal tail:	
Aspect ratio	3.16
Total area, sq ft	35.20
Stabilizer area, sq ft	19.79
Tail incidence, deg	−4
Elevator area (less tab), sq ft	14.66
Elevator tab area, sq ft	0.75
Airfoil section	NACA 0006
Elevator deflection, deg	
Up	31.5
Down	13.5
Elevator tab deflection, deg	
Up	12
Down	31
Vertical tail:	
Aspect ratio	0.88
Total area, sq ft	16.55
Fin area, sq ft	8.78
Rudder area, sq ft	7.77
Airfoil section	NACA 0006
Rudder deflection, deg	
Right	21
Left	21
Tail length (c.g. to rudder hinge; approx.), ft	18.33
Fin offset, deg	0

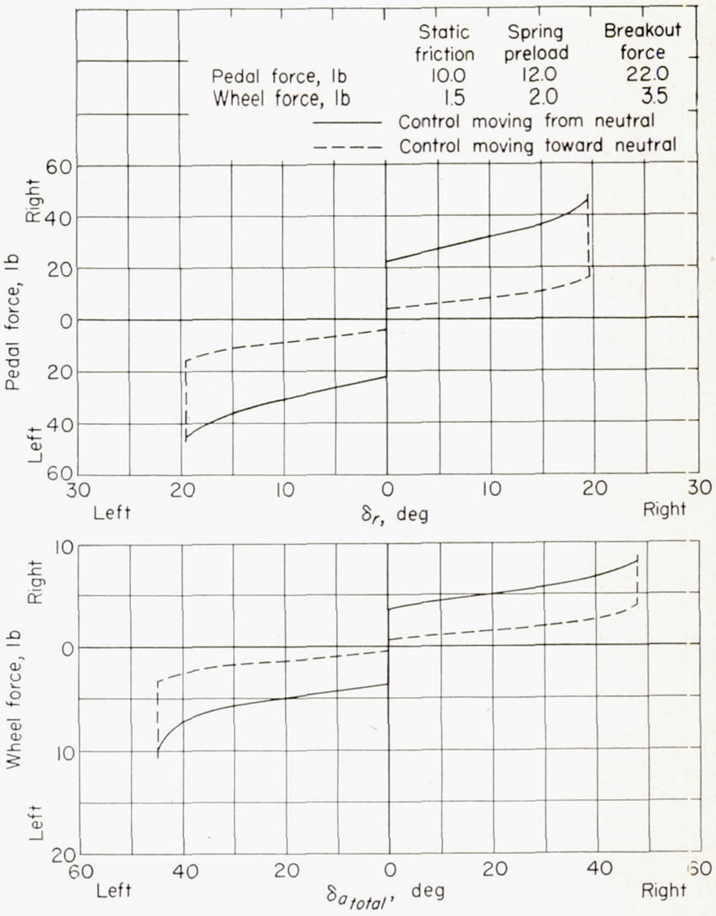


FIGURE 4.—Approximate values of friction, centering spring, and breakout forces in aileron and rudder control systems with centering devices engaged. Forces produced by aerodynamic hinge moments are not included.

cabin within reach of the pilot so that it could be operated manually. Since the rudder system was such as to make installation of the centering springs in the cabin impractical, the rudder centering device was located in the rear of the fuselage. Operation of the rudder device was achieved by means of an electrical actuator controlled by switches mounted on the instrument panel.

The same basic centering unit was used in both the rudder and aileron centering devices. This centering unit, which is shown in figures 6 and 7, consists of a cylindrical barrel enclosing two preloaded compression springs and a shaft passing lengthwise through the center of the barrel. A shoulder is on the shaft and a corresponding shoulder is on the inside of the barrel at its midlength. A flat circular pickup ring under the end of each spring is forced against both shoulders with a force equal to the preload of the spring. The shaft cannot move relative to the barrel without moving one of the pickup rings and consequently compressing the corresponding spring. Inasmuch as the spring being compressed is originally under a preload, a force greater than this preload must be applied before the shaft can be moved. The spring not being compressed by movement of the shaft is retained in its original position by the shoulder of the barrel. When the force applied to displace the shaft is removed, the compression load of the spring forces the shaft back to its original position relative to the barrel.

The application of this device to the rudder control system is shown in figure 6. The barrel is connected to the rudder control horn and the shaft which extends through the opposite end of the barrel is connected to the electrical actuator which is in turn connected to a rigid member of the fuselage frame. When the device is disengaged, movement of the rudder causes the shaft to slide freely forward and rearward within the actuator. When the centering device is engaged, however, this forward and rearward movement of the shaft is restrained by a key that is pulled downward into a groove on the shaft by one of the solenoids. (See sketches at bottom of fig. 6.) To engage the centering device, the pilot energizes the lower solenoid and then uses the rudder pedals to move

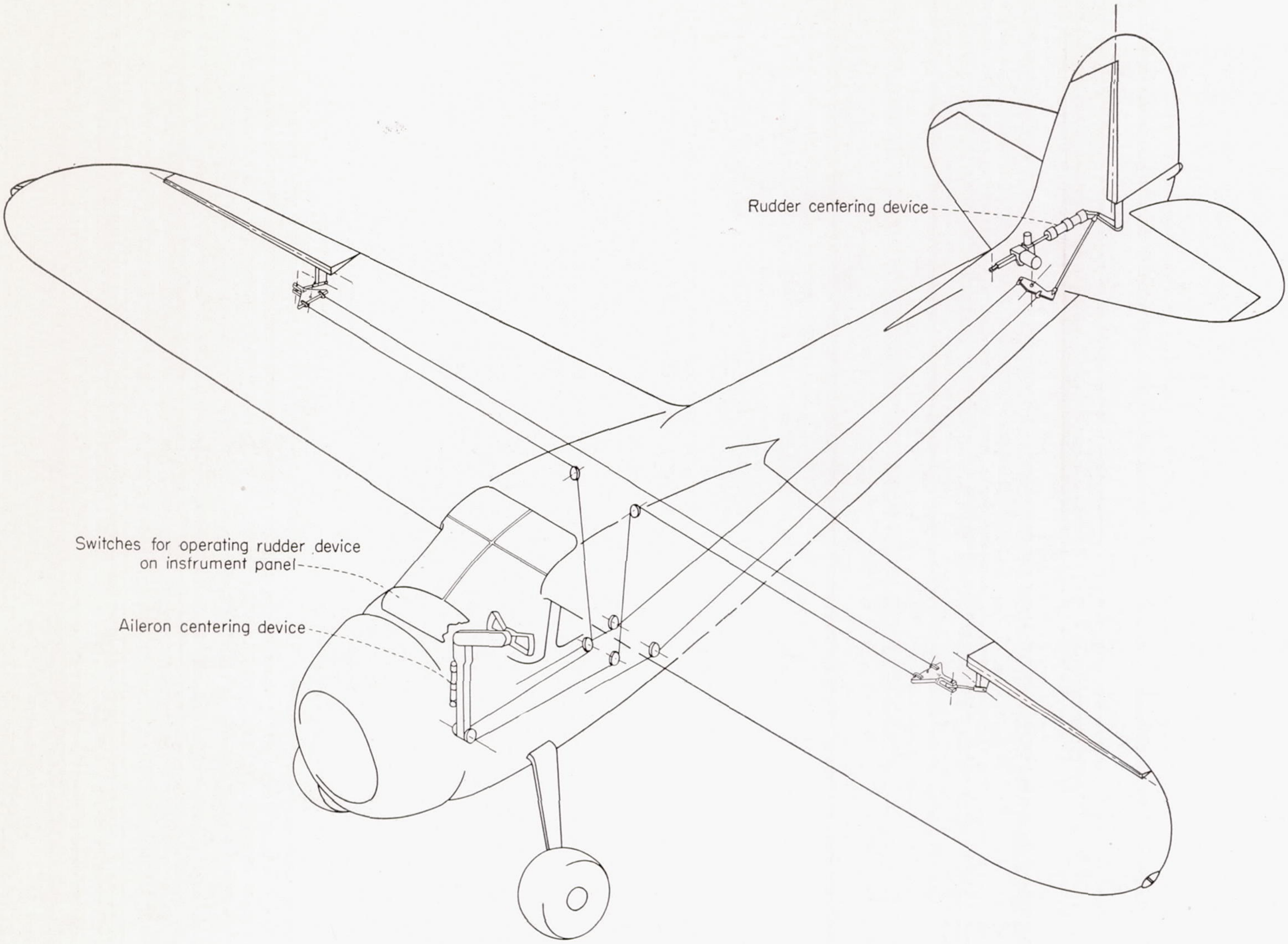


FIGURE 5.—Location of the centering devices relative to the control system.

the shaft until the key is pulled into place when the key and groove are alined. Movement of the rudder causes only the barrel to be moved forward and rearward while the shaft remains fixed. The centering action results from the spring forces which oppose the relative movement of the barrel and the shaft. Trimming of the rudder with the centering device engaged is accomplished by changing the length of the actuator shaft by means of a motor-driven jackscrew. The device is disengaged by means of the other solenoid which pulls the key upward out of the groove. (See fig. 6.)

The application of the centering device to the aileron control system is shown in figure 7. In this case the barrel is fixed rigidly to the control column and the shaft is connected to the aileron cable which runs along the column. The shoulder on the shaft extends through the side of the barrel and forms a yoke. Attached to this yoke is the locking arm through which the control cable passes. The original turnbuckle barrel on the control cable was replaced with a modified barrel which was smooth and cylindrical so that it would slide freely through the hole in the locking arm without catching or binding. When the centering device is disengaged, movement of the ailerons causes the cable and the turnbuckle barrel to move freely through the locking arm. The centering device is engaged by pushing the locking pin of the locking arm through the hole in the turnbuckle barrel. (See sketches at bottom of fig. 7.) The shaft is thus linked into the aileron system and aileron centering is provided by the spring forces opposing relative movement of the shaft and barrel. Trimming of the ailerons with the centering device engaged is accomplished by moving the locking arm relative to the shaft yoke by means of the manually operated jackscrew which connects the yoke and the locking arm. (See sketch at the left of fig. 7.)

Since the control centering devices were designed to be used in the research investigation only and to require as little modification as possible to the airplane structure, they do not necessarily represent devices that would be used in a practical application for light airplanes. Simplification of the installation would be possible by providing manual operation of a rudder centering device located in the cockpit, by

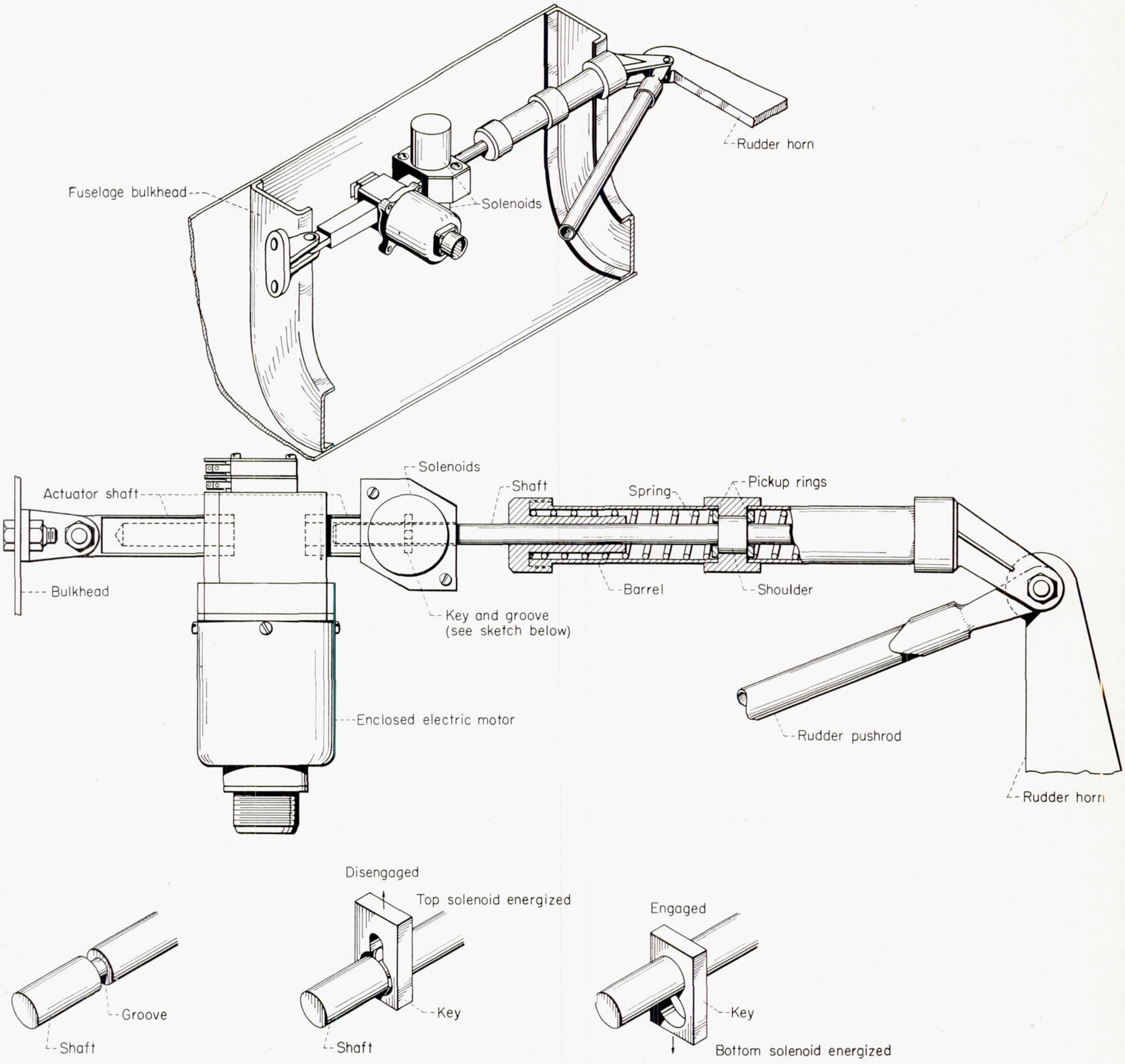


FIGURE 6.—Rudder centering device.

doing away with the disengaging feature which might be considered unnecessary, by using a single spring rather than the double springs, and by designing the centering devices as an integral part of the control system. Of course, if the play in the control system is large, both the aileron and rudder centering devices should probably be located at the control surfaces rather than near the pilot. Complication would result from this arrangement inasmuch as the controls for the centering devices would have to be operated remotely.

TESTS

Several different types of tests were made to determine the apparent spiral stability and the true spiral stability of the airplane. Most of the tests were initiated at altitudes between 4,000 and 5,000 feet, but in tests which ended in spiral dives the altitude decreased rapidly during the tests. All results were obtained in flights in which the air was smooth or moderately rough.

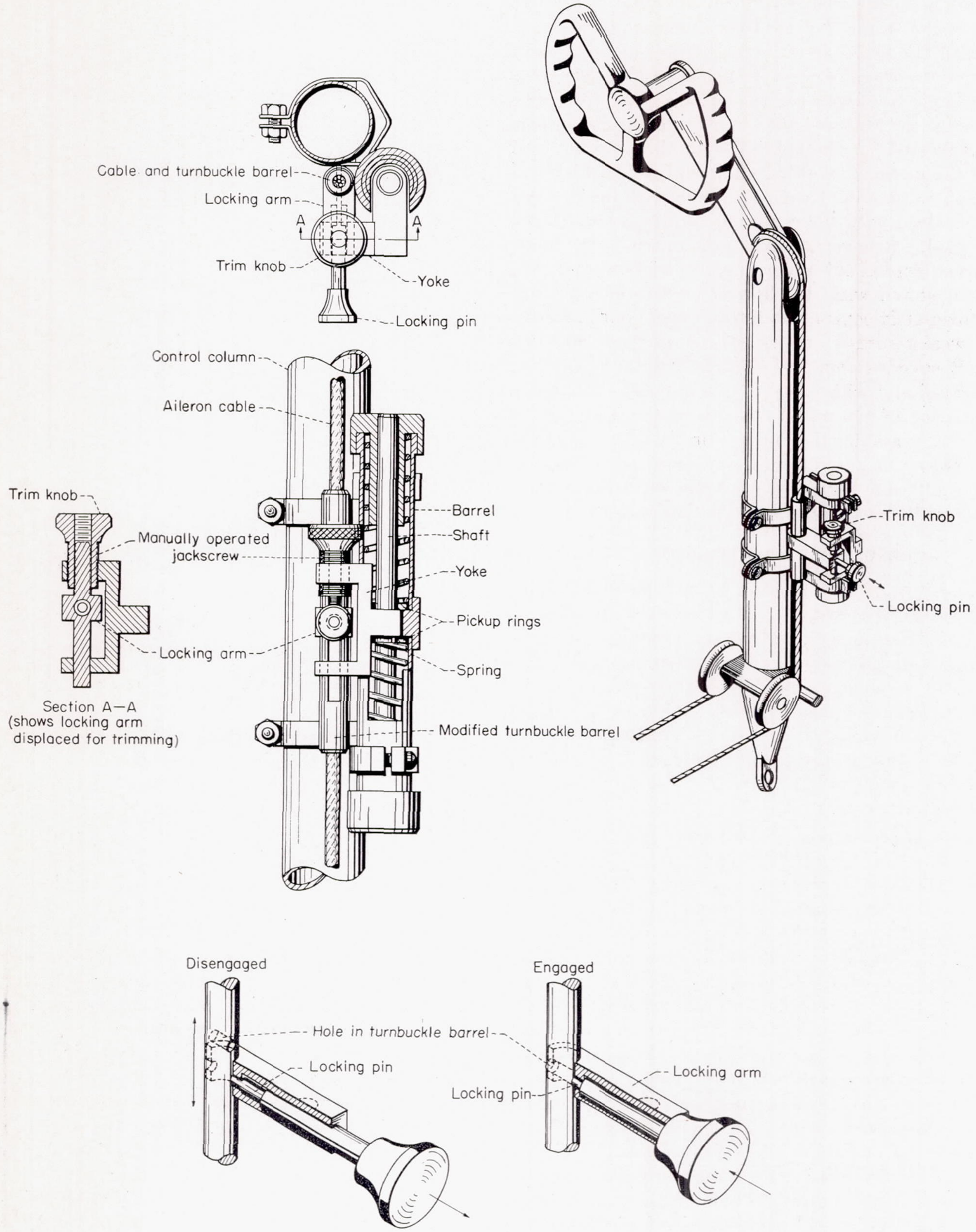


FIGURE 7.—Aileron centering device.

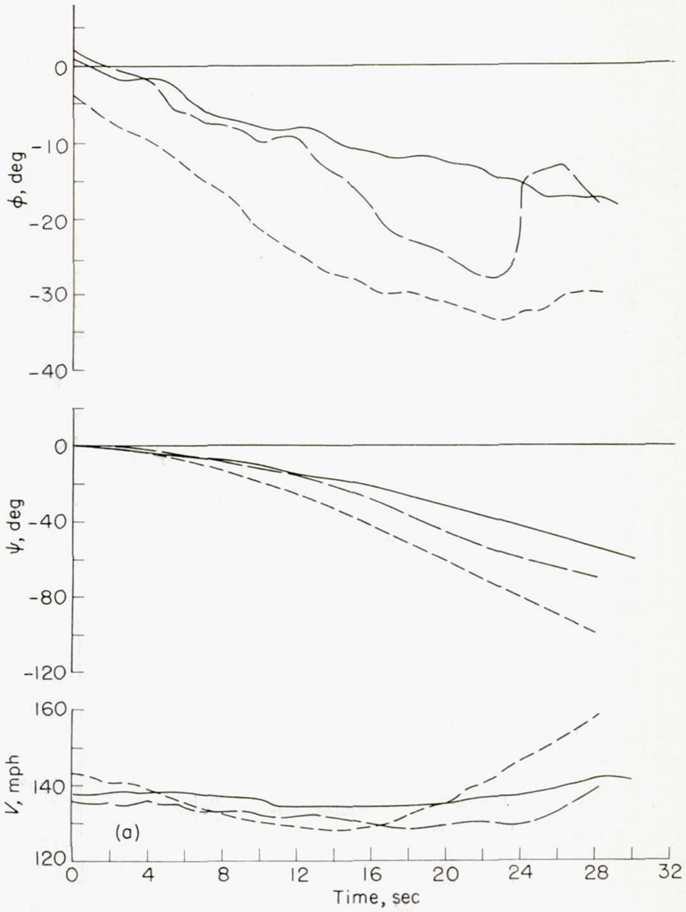
Records of the motions of the test airplane starting from steady wing-level flight at approximately 140 miles per hour were obtained with the aileron and rudder centering springs disengaged and with the elevator free. Similar records were obtained with the wheel free but with the control column used to move the elevator so as to hold the airspeed essentially constant. Recovery records of this type were also obtained with the aileron and rudder centering springs engaged singly and in combination with the elevator free. Records of the motions following an abrupt rudder kick and release at approximately 145 miles per hour with the elevator free were obtained with the centering springs both engaged and disengaged. Recoveries from turns in which the angle of bank was as large as 60° were recorded with both centering springs engaged and with the elevator used to hold the airspeed approximately constant at 150 miles per hour. Similar recoveries were recorded at airspeeds of 120 and 90 miles per hour. Recoveries from banked turns with both centering springs engaged and with elevator free were also attempted with an airspeed of 150 miles per hour at the beginning of the maneuver. In order to obtain a direct indication of the effect of airspeed on lateral trim, tests were also made at airspeeds of 140 and 160 miles per hour with the airplane trimmed laterally for an airspeed of 150 miles per hour.

RESULTS AND DISCUSSION

The results of the investigation have been divided into three main categories: first, results which show the effect of control centering springs on the apparent spiral stability of the airplane; second, results which show the true spiral stability of the airplane at various constant airspeeds with the centering springs engaged; and, third, results which show the effects of changes in airspeed on lateral trim and consequently on the apparent spiral stability. In addition, results are presented which show the effect of centering springs on control forces.

EFFECT OF CONTROL CENTERING SPRINGS ON APPARENT SPIRAL STABILITY

The effect of control centering springs on the apparent spiral stability of the airplane is shown by the flight test results presented in figures 8 and 9. Motions of the airplane starting from steady wing-level flight at approximately 140 miles per hour with the centering springs disengaged and with the aileron and rudder springs engaged singly and in combination are shown in figure 8. Two or three flight records are presented for each condition. Motions following an abrupt rudder kick and release at approximately 145 miles per hour with the springs disengaged and with both springs engaged are shown in figure 9. Two of the principal causes of apparent spiral instability—lack of a means of trimming the airplane and friction in the control system—are illustrated in these two figures. The effect of the control centering springs in correcting these deficiencies is also shown.

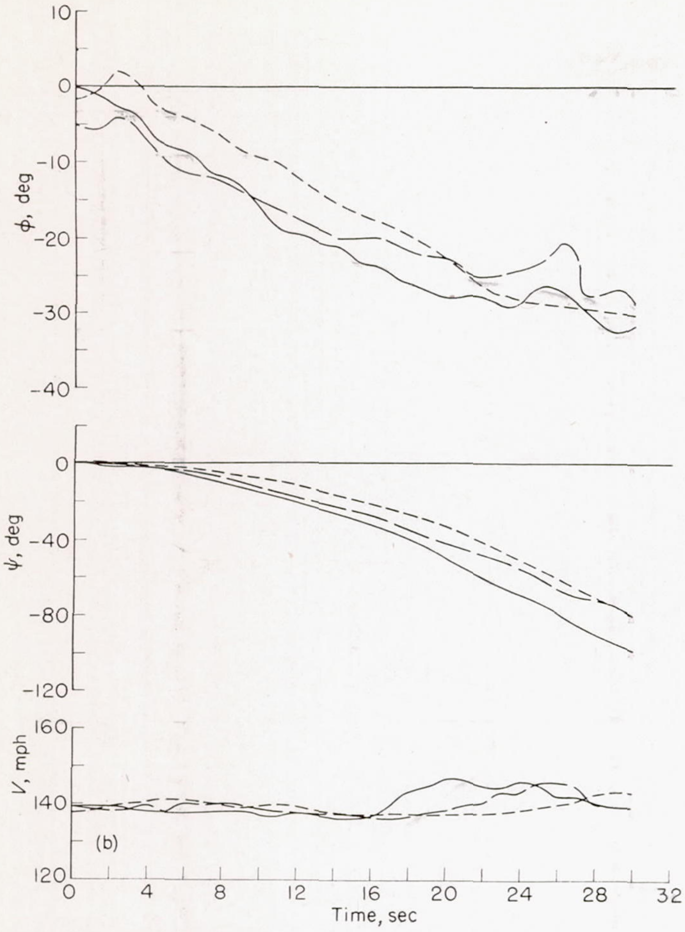


(a) Aileron and rudder springs disengaged. Elevator free.

FIGURE 8.—Motions of the airplane with aileron and rudder controls released starting from steady wing-level flight at approximately 140 miles per hour. Results of several flight records are shown.

Effect of centering springs on lateral trim.—The data of figure 8 (a) for the airplane with the centering springs disengaged and the elevator free show that the uncontrolled motion was a spiral to the left and that at the end of about 30 seconds a bank angle of about 20° or 30° was reached. This apparent spiral instability was not reduced when the pilot controlled the elevator to keep the airspeed approximately constant at 140 miles per hour. (See fig. 8 (b).) The data of figures 8 (c) and 8 (d) show that engaging only the aileron centering springs provided no substantial improvement in the uncontrolled motions but that engaging only the rudder centering springs almost entirely eliminated the spiral tendencies of the airplane. For this airplane, therefore, the most important out-of-trim moments with controls free were apparently produced by the rudder. With both the aileron and rudder springs engaged (fig. 8 (e)) the uncontrolled motion of the airplane was slightly better than that obtained with only the rudder springs engaged, at least with regard to the change in heading.

In these flights with both the rudder and aileron springs engaged the airplane would fly "hands off" for indefinite

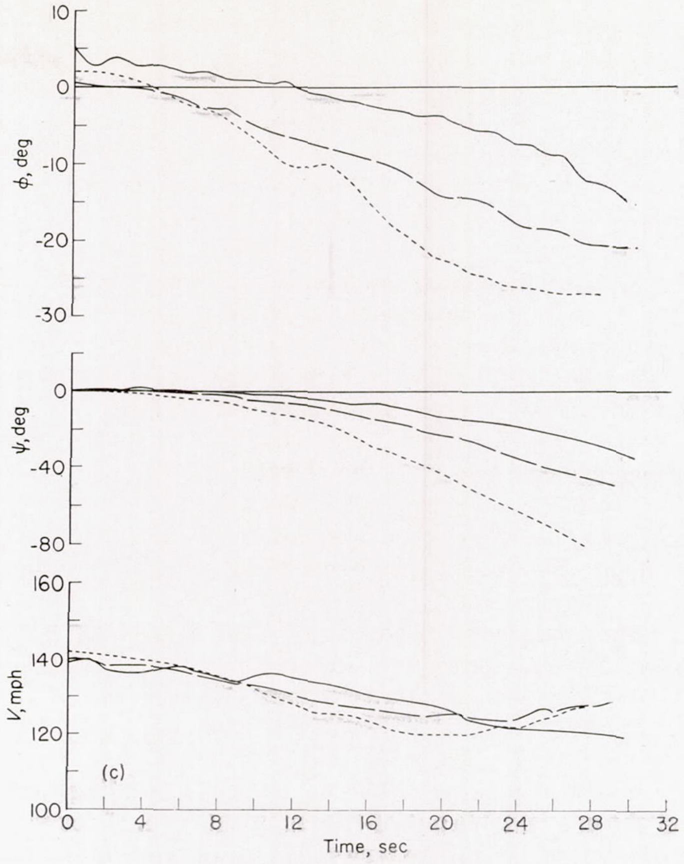


(b) Aileron and rudder springs disengaged. Elevator used to hold airspeed at approximately 140 miles per hour.

FIGURE 8.—Continued.

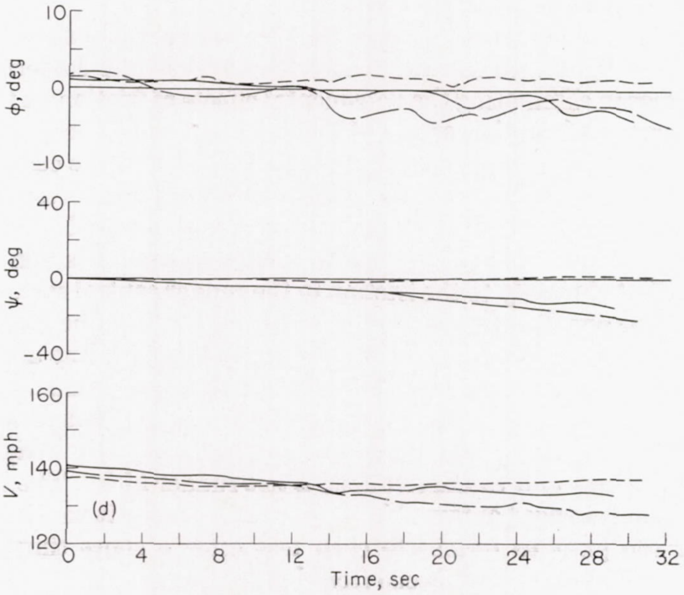
periods of time without getting into a dangerous attitude. This result clearly indicates that the airplane was spirally stable at this airspeed (140 mph) and that the tendency of the airplane toward spiral divergence without centering springs engaged was only apparent spiral instability caused by the rolling and yawing moments resulting from the out-of-trim positions assumed by the free controls.

The results obtained with both the aileron and rudder springs engaged also illustrate the point brought out in reference 2 that, although a spirally stable and well-trimmed airplane will be safe with regard to spiral tendencies and will be fairly good with regard to maintenance of heading, it cannot be expected to maintain a given heading indefinitely unless it is equipped with an autopilot. For example, the data of figure 8 (e) show that, at the end of 30 seconds, random gust disturbances, and perhaps very slight out-of-trim control settings, had caused the airplane to change heading 6° or 7°. Even in perfectly smooth air, continuous maintenance of course could probably never be achieved without an autopilot because perfect trim is never likely to



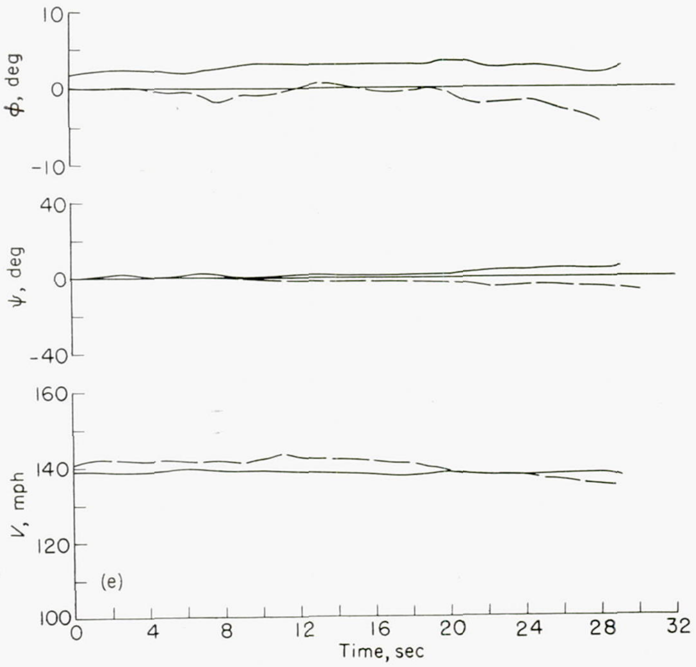
(c) Aileron spring only engaged. Elevator free.

FIGURE 8.—Continued.



(d) Rudder spring only engaged. Elevator free.

FIGURE 8.—Continued.

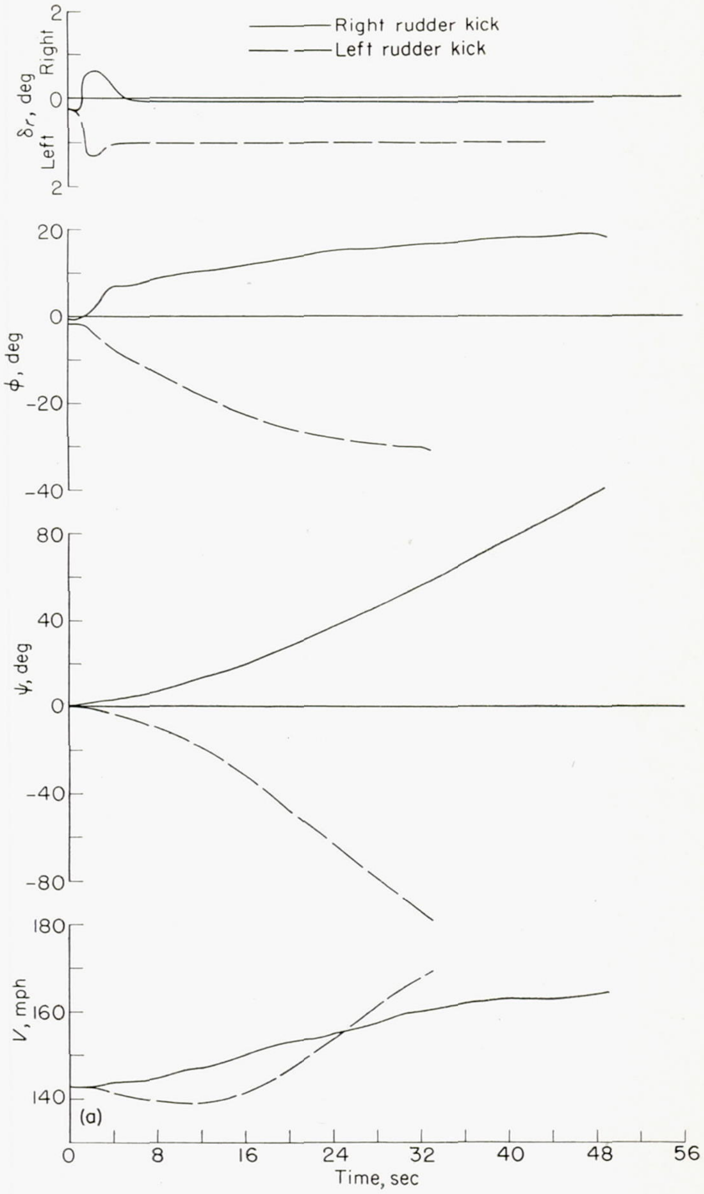


(e) Aileron and rudder springs engaged. Elevator free.

FIGURE 8.—Concluded.

be obtained in practice. The deviations in heading caused by slight unavoidable out-of-trim moments can, of course, be reduced by increasing the true spiral stability of the airplane as pointed out in reference 2. The apparent spiral stability can also be improved by minimizing the lateral trim changes caused by changes in airspeed, power, and fuel loading. The effect of airspeed on lateral trim for the test airplane is discussed in a subsequent section.

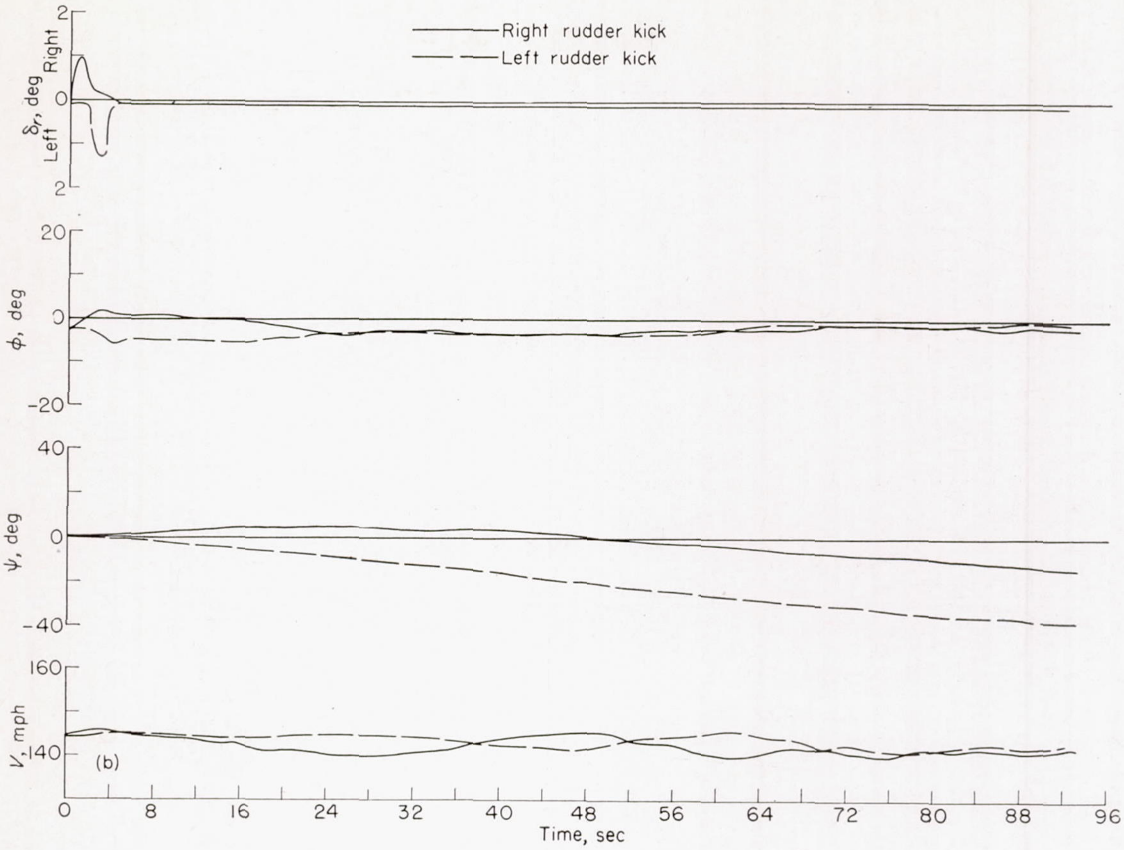
Effect of centering springs in overcoming friction.—The data of figure 9 illustrate clearly the effect of the centering springs in eliminating the detrimental effects of friction on the uncontrolled motion of the airplane after a rudder kick and release. The curves of figure 9 (a) show that with the centering springs disengaged the rudder did not return to the original position after being deflected and released. This failure of the rudder to return to the original position is attributed mainly to the friction in the rudder control system, but, for one direction of rudder deflection, it could be partly caused by the tendency of the rudder to float at some angle other than that required for trim. The yawing moments resulting from this out-of-trim rudder position caused the airplane to go into a spiral dive to the right after a right rudder kick and to the left after a left rudder kick. The increasing airspeed obtained in the spiral dive made it necessary for the pilot to terminate each test after a short time to prevent excessive airspeeds from being reached.



(a) Aileron and rudder centering springs disengaged.

FIGURE 9.—Motions following abrupt rudder kick and release. Elevator free. V=145 miles per hour (approx.) at start of maneuver.

The results presented in figure 9 (b) for the airplane with the centering springs engaged show that the rudder returned to the original position after being deflected and released and that the subsequent motions of the airplane were greatly different from those obtained with centering springs disengaged. The airplane recovered quickly from the relatively small angles of bank reached during the rudder kicks with the springs engaged and then appeared to be capable of maintaining an essentially wing-level attitude for an indefinite



(b) Aileron and rudder centering springs engaged.

FIGURE 9.—Concluded.

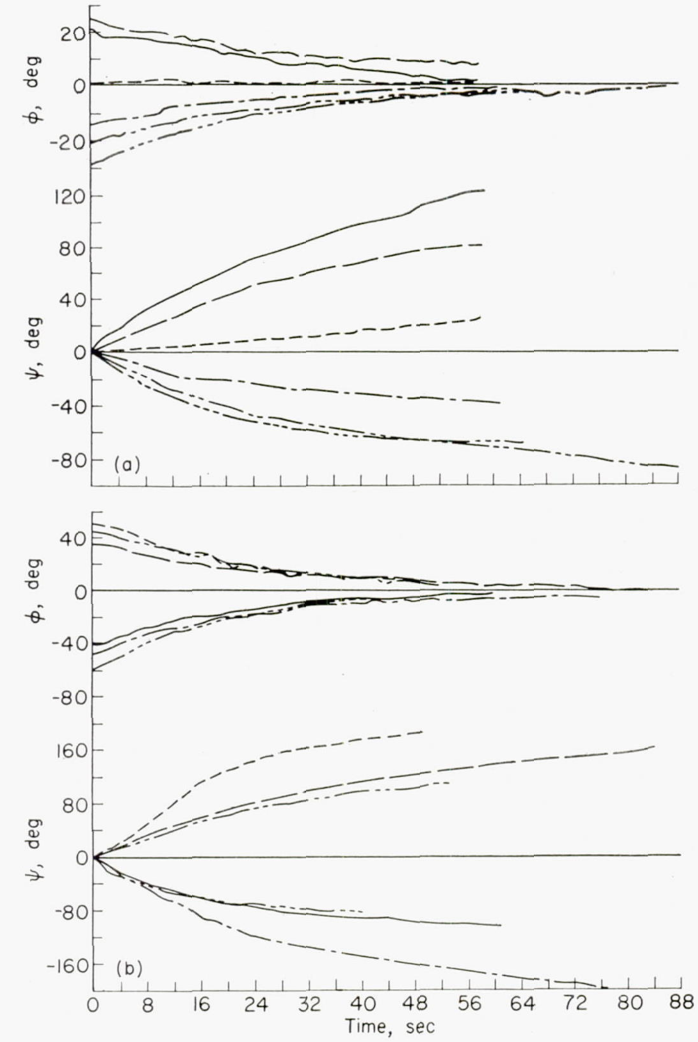
period. The airspeed varied only slightly during these tests and the changes in heading were relatively small compared with those which occurred when the centering springs were disengaged. The asymmetry of the curves for heading (ψ) in figure 9 (b) indicates that the airplane was not trimmed for straight flight but rather for a flat left turn when these records were obtained.

TRUE SPIRAL STABILITY OF THE AIRPLANE WITH CONTROL CENTERING SPRINGS ENGAGED

The results of the flight tests made to determine the true spiral stability of the airplane with the centering springs engaged and with the elevator used to hold the airspeed approximately constant are presented in figures 10 and 11. The motions of the airplane during recoveries from various angles of bank up to 60° at an airspeed of 150 miles per hour are shown in figure 10. Similar records of recoveries from bank angles of 10° or less at airspeeds of 120 and 90 miles per hour are presented in figure 11. The time required for the bank angle to decrease to one-half amplitude was determined from the average of the recoveries from both right and left bank angles.

The data of figure 10 indicate that the airplane had a moderate amount of spiral stability at 150 miles per hour since recoveries to an almost wing-level attitude from angles of bank as large as 60° were effected in approximately 1 minute. The average time required for the bank angle to decrease to one-half amplitude appears from the records to be about 15 or 20 seconds.

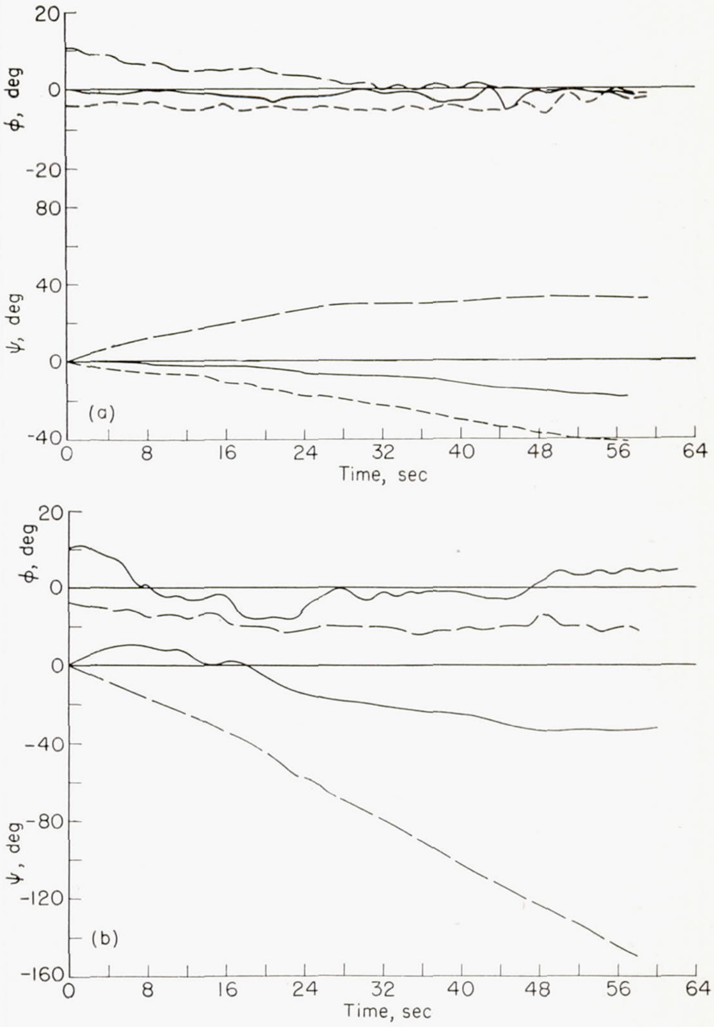
The data of figure 11 show that as the airspeed was reduced the spiral stability decreased. The results of figure 11 (a) indicate that the airplane was still spirally stable at 120 miles per hour but that the time required for the angle of bank to decrease to one-half amplitude (25 or 30 sec) was somewhat greater than that for 150 miles per hour. The pilot reported that the rapid recovery to a wing-level attitude near the end of the test that started with a 4° left bank was caused by a gust and was thus not a true indication of the spiral stability of the airplane at this airspeed. The data of figure 11 (b) indicate that a definite reduction in spiral stability occurred when the airspeed was reduced to 90 miles per hour. These results do not show conclusively whether the airplane was stable or unstable at this airspeed, but they



(a) Initial bank angles less than 30°.

(b) Initial bank angles greater than 30°. (Note change in vertical scale.)

FIGURE 10.—Recovery from banked turns with aileron and rudder controls released. Aileron and rudder springs engaged. Elevator used to hold airspeed at approximately 150 miles per hour. Results of several flight records are shown.



(a) V=120 miles per hour (approx.).

(b) V=90 miles per hour (approx.).

FIGURE 11.—Effect of airspeed on the recovery from banked turns with aileron and rudder controls released. Aileron and rudder springs engaged. Elevator used to hold airspeed approximately constant at values given. Results of several flight records are shown.

do indicate that, since the degree of stability or instability was evidently slight, the airplane could be considered about neutrally stable.

A comparison of the measured and calculated spiral stability of the airplane is presented in figure 12 in terms of the reciprocal of the time to damp to one-half amplitude for the spiral mode. The calculations were made by the method described in reference 3. The mass and aerodynamic parameters used in the calculations are given in table II. The stability derivatives were estimated by the methods described in reference 3 and an approximate check of the derivatives C_{n_β} and C_{l_β} was obtained from flight test data on the airplane.

The data of figure 12 indicate that the measured spiral stability was somewhat greater than the calculated stability at all airspeeds and that the measured variation in stability with airspeed was greater than the calculated variation. The experimentally determined values are in qualitative agreement with the theoretical values in showing a reduction in spiral stability with decreasing airspeed. The failure to obtain better quantitative agreement can be attributed partly to possible inaccuracies in the estimation of some of the stability derivatives and partly to the lack of good quantitative experimental data, particularly at 120 and 90 miles per hour.

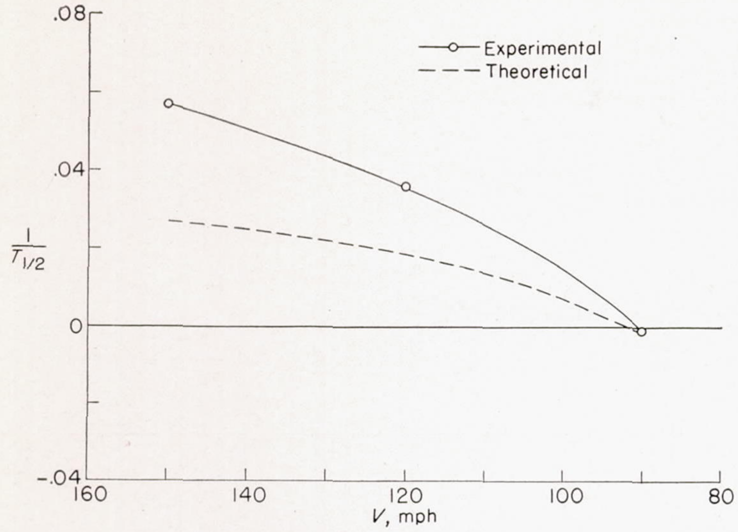
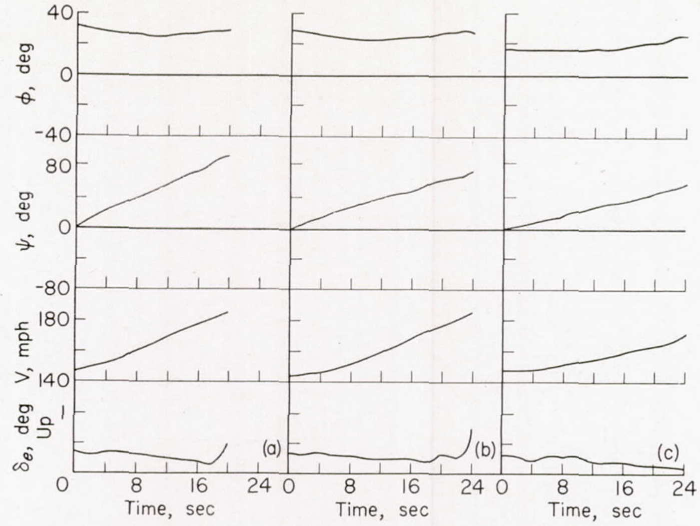


FIGURE 12.—Comparison of experimental and theoretical values of the reciprocal of the time to damp to one-half amplitude for the spiral mode.

TABLE II.—MASS AND AERODYNAMIC PARAMETERS USED IN SPIRAL-STABILITY CALCULATIONS

[The parameters γ, C_{Y_p}, and C_{Y_r} were assumed to be zero]

Parameter	Airspeed (mph)		
	150	120	90
C_L	0.26	0.40	0.71
α, deg	0.8	2.6	6.5
η, deg	−1.2	0.6	4.5
K_X^2	0.0110	0.0110	0.0110
K_Z^2	0.0230	0.0230	0.0230
K_{XZ}	−0.0002	0.0001	0.0009
μ_b	5.80	5.80	5.80
C_{n_β}	0.05	0.05	0.05
C_{l_β}	−0.07	−0.07	−0.07
C_{Y_β}	−0.28	−0.28	−0.28
C_{n_p}	−0.013	−0.023	−0.042
C_{l_p}	−0.43	−0.43	−0.43
C_{n_r}	−0.100	−0.102	−0.109
C_{l_r}	0.07	0.09	0.16



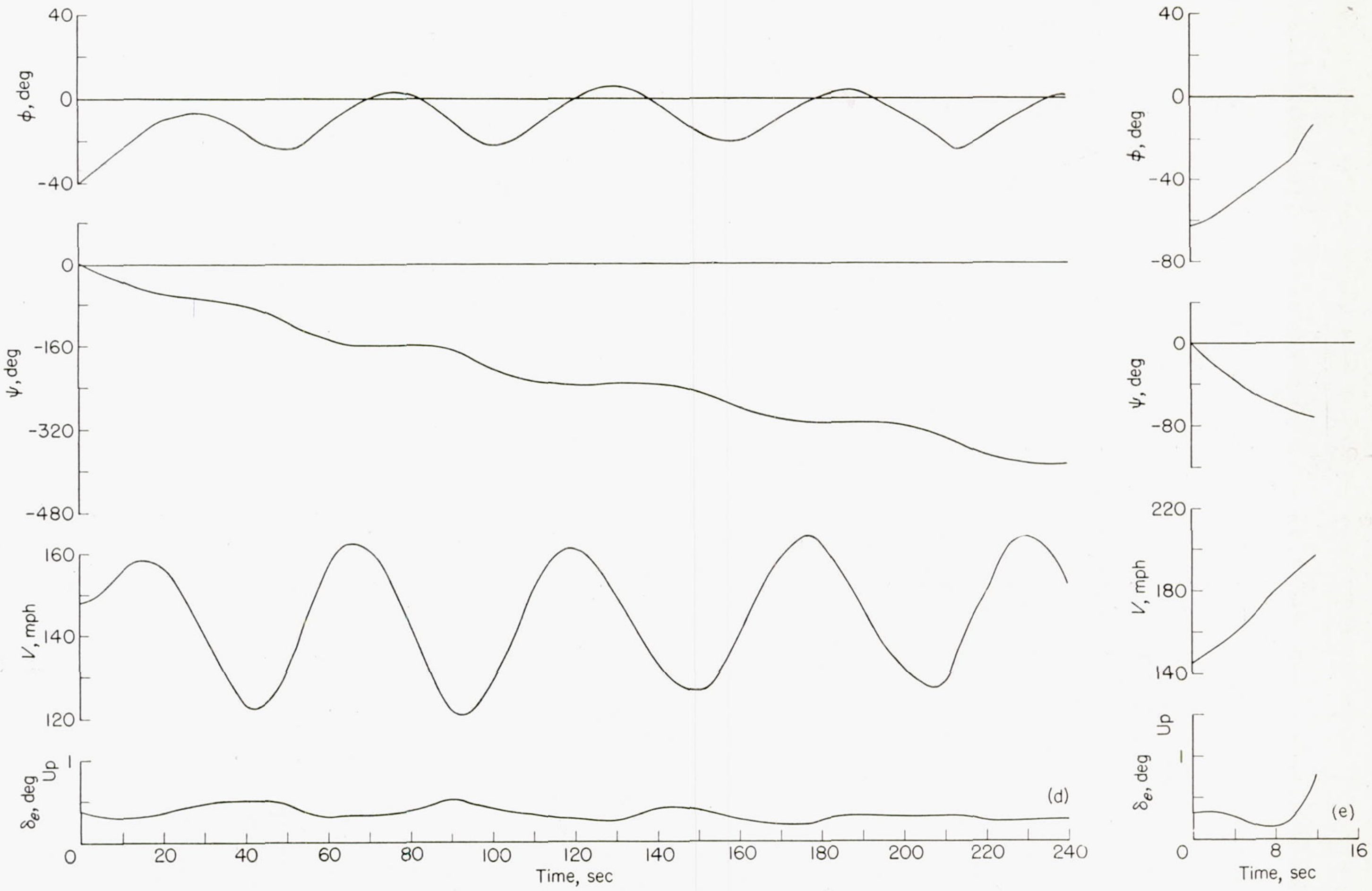
(a) Initial bank angle approximately 30° right.
(b) Initial bank angle approximately 30° right.
(c) Initial bank angle approximately 20° right.

FIGURE 13.—Attempted recovery from banked turns with aileron and rudder controls released. Aileron and rudder springs engaged. Elevator free. $V=150$ miles per hour (approx.) at start of each record.

EFFECTS OF CHANGES IN AIRSPEED ON LATERAL TRIM AND APPARENT SPIRAL STABILITY

The motions of the airplane during recovery from banked turns with the centering springs engaged but with the elevator free are shown in figure 13. These records were obtained under the same conditions as those of figure 10 except that the elevator was free in this case; whereas the elevator was used to hold the airspeed constant in the tests recorded in figure 10. The results of figure 13 show that when the elevator was free the airspeed varied greatly during the recoveries from the banked turns and the motions of the airplane were entirely different from those shown in figure 10. A comparison of the results of figures 13 (a), 13 (b), and 13 (c) with those of figures 13 (d) and 13 (e) shows that the recoveries from right banked turns were greatly different from the recoveries from left banked turns when the elevator was free; whereas all the recoveries were quite similar when the airspeed was held constant. (See fig. 10.)

The results of figure 13 can be explained more clearly by first considering the results of figures 14 and 15, which show the effects of airspeed on lateral trim. The data of figure 14 show the aileron, rudder, and elevator deflections required to trim the airplane in level flight at various airspeeds. These data show that the change in aileron trim with airspeed was slight but that a sizable change in rudder trim was required with changes in airspeed. The change in the required rudder trim was such that more left rudder was required with increasing airspeed. Or, expressed differently, the required trim change was such that increases in airspeed with the rudder held fixed would cause the airplane to be out of trim to the right. This effect is illustrated by the flight records presented in figure 15. All these records were obtained with the centering springs engaged and with the airplane trimmed laterally and directionally for an airspeed of 150 miles per hour. When the airspeed was held at 150 miles per hour, the airplane maintained an essentially wing-level attitude; but when the elevator setting and power were varied to increase or decrease the airspeed, the airplane started a gentle spiral to the right or left. At an airspeed of 160 miles per hour a steady right turn at 20° bank was reached and at 140 miles per hour a steady left turn at 10° bank was reached. The data of figure 14 indicate that these turns were produced by out-of-trim rudder settings of less than 0.1° in each direction.



(d) Initial bank angle approximately 40° left. (Note change in scales.)

(e) Initial bank angle approximately 60° left.

FIGURE 13.—Concluded.

The critical nature of the lateral and directional trim problem is apparent from these results.

The data of figures 14 and 15 can now be used to explain the results presented in figure 13. The records presented in figures 13 (a), 13 (b), and 13 (c) for attempted recoveries from banked turns to the right with elevator free indicate that the airplane had little or no tendency to recover from the turn; that is, the bank angle remained approximately constant. In all these tests the pilot had to terminate the test after only a very short time to prevent excessive airspeeds from being reached. The failure to recover from these right turns is attributed to the out-of-trim moments to the right caused by the increasing airspeed. These moments opposed and were apparently about equal to the restoring moments produced by the inherent spiral stability of the airplane.

The records presented in figures 13 (d) and 13 (e) for recoveries from banked turns to the left with elevator free show that initially the airspeed increased and the airplane recovered rapidly toward a wing-level attitude. In these cases the out-of-trim moments to the right caused by increased airspeed apparently reinforced the restoring moments to the right produced by spiral stability so that rapid recoveries were obtained. The recoveries were not considered satisfactory, however, because in one case (fig. 13 (d)) a virtually undamped longitudinal-lateral oscillation was obtained and in the other case (fig. 13 (e)) the pilot had to stop the recovery before 0° bank was reached because the airspeed became excessive.

The flight record presented in figure 13 (d) is particularly interesting in that it shows the interaction of the longitudinal and lateral motions of the airplane. The period of the motion (approx. 55 sec) appears to be about the same as that of the phugoid or long-period longitudinal oscillation which is usually a rather lightly damped motion. The fluctuations in airspeed during the longitudinal oscillation apparently produced out-of-trim moments alternately to the right and left which caused the airplane to roll back and

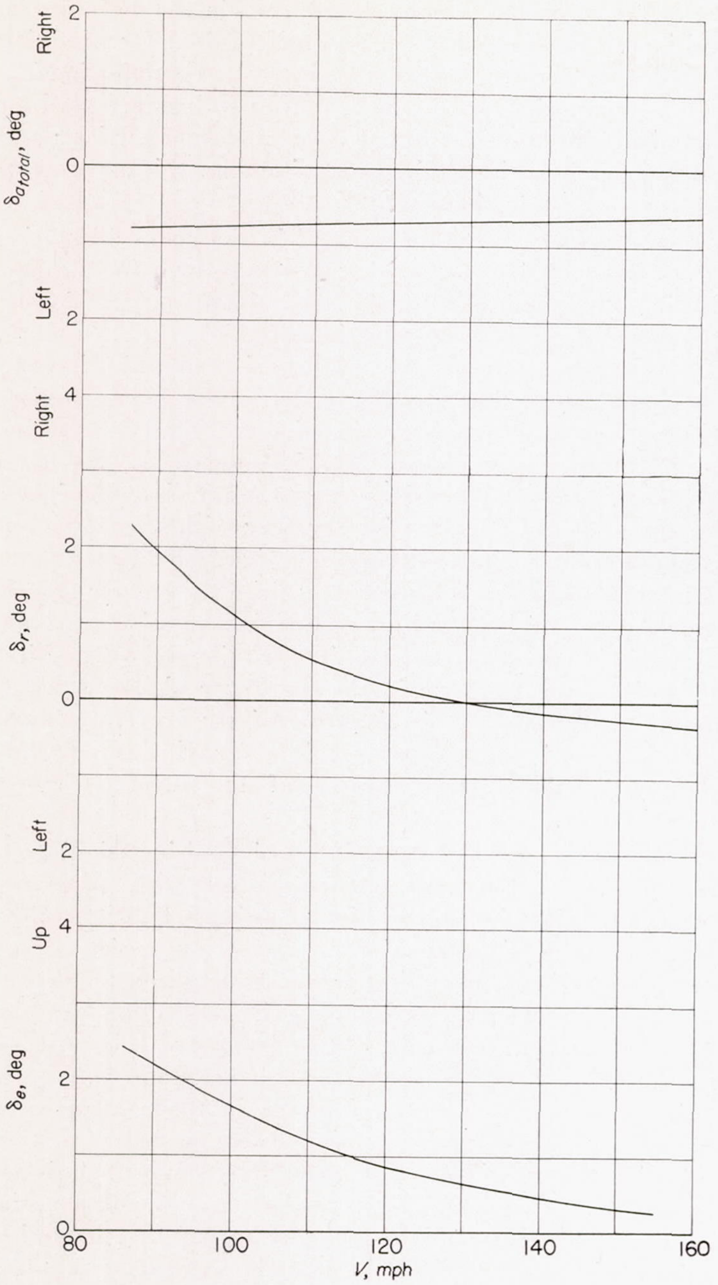


FIGURE 14.—Variation with airspeed of the control-surface deflections required for trim.

forth between about 0° and 20° left bank with the same 55-second period and to have similar periodic changes in heading. Since the oscillation in bank would, in turn, be expected to cause changes in airspeed (increased airspeed with increased bank angle) and since a certain amount of lag is inherent in these interactions between airspeed and bank angle, it does not appear surprising that the undamped longitudinal-lateral oscillation occurred.

Although all the flight tests were made in smooth or moderately rough air, an indication of the apparent spiral stability characteristics of the airplane in very rough air can probably be obtained from the data presented in figures 10 and 13. These results indicate that recovery from the large angles of bank that are likely to be produced by large gust disturbances will probably not be satisfactory unless the airspeed is held essentially constant by use of the elevator. Therefore, the previously mentioned results which indicated that the airplane with both centering springs engaged would fly "hands off" for indefinite periods of time without getting into a dangerous attitude might not apply to flights in very rough air.

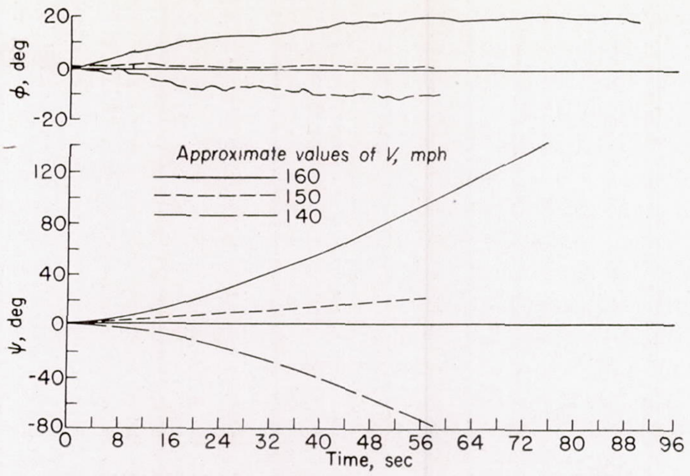


FIGURE 15.—Effect on the lateral motions of increasing or decreasing the airspeed from the airspeed at which the airplane is trimmed laterally and directionally (150 mph). Aileron and rudder springs engaged. Elevator used to hold airspeed approximately constant at values shown.

All the records of figure 13 show that the free elevator generally tended to float to a lower setting with increasing airspeed, an indication that the stick-free longitudinal stability was less than the stick-fixed longitudinal stability. This change in elevator position with airspeed aggravated the tendency of the airplane to increase airspeed in the turn. No flights were made in which an attempt was made to hold the elevator fixed during recoveries from banked turns, but it is believed that such recoveries would be better than those obtained with elevator free. Therefore, it appears that control centering springs in the elevator system might provide some improvement in the apparent spiral stability. Even with the elevator fixed, however, the airspeed will vary during recoveries from banked turns so that the use of elevator centering springs should not be expected to lead to recoveries as good as those obtained with the airspeed held constant. If elevator centering springs are used, consideration should be given to possible detrimental effects of such springs on the elevator control-force characteristics.

On the basis of the results of this investigation, it appears that the changes in lateral and directional trim produced by changes in airspeed, power, and fuel loading must be minimized before completely satisfactory results can be expected from control centering springs. For the best results it appears, also, that the true spiral stability should be greater than that for the test airplane since very small out-of-trim deflections were shown to produce rather large angles of bank. The determination of what constitutes satisfactory apparent and true spiral stability was considered beyond the scope of this investigation, which was concerned primarily with whether control centering springs could make the apparent spiral stability as good as the true spiral stability. Some indication of the improvement in spiral stability that will result from various modifications to the airplane can be obtained from the methods and data presented in reference 2.

EFFECT OF CENTERING SPRINGS ON CONTROL FORCES

The nonlinear force variation provided by the positive-action preloaded centering springs (fig. 1) caused a corresponding nonlinear variation of control forces when the centering springs were engaged. This nonlinearity caused a noticeable "bump" in the control forces as the controls were moved through the neutral position and caused an increase in the breakout control force required to deflect the control from the centered position. (See fig. 4.) In the case of the ailerons, the static friction was fairly small (about 1.5-lb wheel force) so that the spring preload used was not sufficient to make the "bump" or the increased breakout force (about 3.5-lb wheel force) objectionable to the pilots. In the case of the rudder, however, the static friction was large (about 10-lb pedal force) and the spring preload required was correspondingly large so that the breakout force was about 22 pounds. Since this increase in rudder breakout force increased the difficulty of making smoothly coordinated turns with the airplane, the rudder control-force characteristics were not considered entirely satisfactory by the pilots.

Since the breakout control force required to deflect the controls from the centered position is a function of the static friction and the spring preload and since the spring preload required is in turn a function of the static friction, it is apparent that the static friction in the control system must be kept small to avoid objectionably large breakout control forces. Revision of the rudder control system of the test airplane to reduce the static friction was considered beyond the scope of the present investigation. It is felt, however, that if this friction were substantially reduced, the resulting reduction in spring preload required and, hence, in the breakout force would probably eliminate the objections to the rudder control-force characteristics of the test airplane.

Use of the centering springs as a means for trimming the controls requires an additional amount of preload to provide the forces necessary to hold the controls in the desired trim positions. If this additional preload required for trimming is large, the control forces are likely to be objectionably high. In addition, when the centering springs are used for trimming, the breakout forces become unsymmetrical; and if a large preload is required for trimming, this asymmetry is likely to be objectionable.

In the present tests, the preload in the rudder centering device was sufficient at cruising speeds to trim the airplane in wing-level flight. Although, as pointed out previously, the breakout forces were objectionably high, the asymmetry in the breakout forces was not considered objectionable. The rudder deflection, and hence the rudder force, required for trim increased with decreasing airspeed (fig. 14), however, so that the rudder preload was inadequate at the lower airspeeds. In order to trim at these lower airspeeds it was necessary to use aileron trim together with the maximum available rudder trim and to fly in a slightly banked attitude rather than with the wings level. Since the rudder preload required at cruising speeds resulted in excessive breakout forces, it is apparent that the increase in preload required for satisfactory rudder trim at the lower airspeeds would result in even more objectionable rudder breakout forces. This increase in the preload required for trim would probably also make the asymmetry of the breakout forces objectionable.

Another factor which must be considered in designing for satisfactory control-force characteristics with preloaded centering springs is the variation of spring force with control deflection. In this connection, one important design parameter is the ratio of the spring deflection required to produce the desired preload to the total spring deflection resulting from full control deflection. Small values of this ratio are likely to produce excessively large control forces. If the ratio is large, however, the increase in the control forces caused by the centering springs will probably not be objectionable provided, of course, that the preload is not very large. It appears therefore that the use of a spring that must be almost fully compressed to produce the desired preload will probably result in the most satisfactory control-force characteristics.

For some airplanes, particularly those that have large amounts of friction in the control system and hence require centering springs with large amounts of preload, some provision might be desirable for disengaging the centering devices at take-off and landing and during extensive maneuvering or acrobatics. The most satisfactory installations will probably be obtained, however, when the friction in the control system is reduced enough to permit the use of permanently engaged centering devices.

CONCLUDING REMARKS

The results of the investigation to determine the effect of control centering springs on the apparent spiral stability of the typical high-wing personal-owner airplane may be summarized as follows:

1. Although the airplane was spirally stable over most of the speed range with the controls held in the trim position, it appeared to be spirally unstable with controls free and with the centering springs disengaged because of the moments produced by out-of-trim control positions. (The aileron and rudder control surfaces did not have trim tabs that could be adjusted in flight.) After an abrupt rudder kick and release, the airplane appeared to diverge in the direction of the rudder kick because friction prevented the rudder from centering.

2. Control centering springs (with provision for trimming) definitely improved the apparent spiral stability of the airplane by making it possible to trim the airplane laterally and by preventing the aileron and rudder surfaces from being held in an out-of-trim position by friction. With both centering springs engaged to hold the controls in the exact trim positions the airplane would fly "hands off" for indefinite periods of time without getting into a dangerous attitude, at least, in the smooth and moderately rough air in which all the tests were made.

3. The true spiral stability of the airplane with the controls held in the trim position decreased with decreasing airspeed and the airplane appeared to have approximately neutral stability at 90 miles per hour. The measured spiral stability was somewhat greater than that indicated by theory.

4. When the elevator was used to keep the airspeed constant, the apparent spiral stability was the same in both directions. When the airspeed was not held constant (elevator free), however, the airspeed initially tended to increase after the release of the controls when the airplane was in a banked attitude. The trim change resulting from the increased airspeed tended to bank the airplane to the right. This tendency caused the airplane to have more apparent spiral stability in a left bank but produced a spiral divergence in large angles of bank to the right. When the elevator was free it tended to float to a lower setting, an effect which aggravated the tendency of the airplane to increase airspeed in a bank. Because of the critical effect of airspeed on lateral and directional trim, it appeared that control centering springs on the elevator would provide some improvement in apparent spiral stability. The unsatisfactory recoveries from large angles of bank with the elevator free indicated that the airplane might not fly satisfactorily "hands off" in very rough air.

5. The results of the investigation indicate that in order to get completely satisfactory results with control centering springs it will probably be necessary to minimize lateral-directional trim changes due to changes in airspeed, power, and fuel loading and to increase the true spiral stability of the airplane.

6. The effect of the centering springs on the aileron control-force characteristics was not considered objectionable by the pilots since the breakout force (friction plus spring preload) was relatively small (approx. 3.5-lb wheel force). The rudder force characteristics, however, were considered objectionable because the excessive friction in the rudder control system required the use of a large preload and consequently resulted in a large breakout force (approx. 22-lb pedal force).

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *March 22, 1951.*

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