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FLIGHT MEASUREMENTS OF THE FLYING QUALITIES OF FIVE LIGHT AIRPLANES

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SUMMARY

Results are presented of an investigation made to determine measurements of stability, controllability, and stalling characteristics of five light airplanes.

Comparison of the characteristics of these airplanes with the requirements for satisfactory flying qualities leads to the following conclusions:

The five airplanes were stable longitudinally in most of the conditions tested. The degree of stability varied considerably among the five airplanes, but the up-elevator position required to stall with power on was low relative to the maximum deflection of the elevator.

The control surfaces of all the airplanes were satisfactorily effective in producing changes in attitude and angular velocity about their respective axes.

Wide variations in directional stability were encountered among the five airplanes. The adverse yaw was considered objectionable on the airplanes which had low directional stability.

The dihedral effect was positive and generally within desirable limits for all the airplanes tested. The bank accompanying sideslip was favorably large even at low speeds for all airplanes.

The pitching moment due to sideslip was generally desirably small at small angles of sideslip, although at large angles of sideslip an appreciable nosing-down tendency was measured on several of the airplanes.

Stall warnings were considered good for all five airplanes, although the ensuing instability which consisted of a rapidly increasing rolling and yawing oscillation at the complete stall was considered objectionable. The stall warning in general consisted of buffeting, increased stick force, and rearward stick travel, although these last two characteristics were rather small with power on. The

ailerons were ineffective in maintaining lateral control in a power-on stall in any of the airplanes. Recovery from the stalled condition was easily made on all airplanes by pushing the elevator control forward.

Stalls from turning flight were possible with power on at all speeds in three of the four airplanes tested but were generally impossible above a certain airspeed with power off because sufficient elevator control was not available. The initial roll-off in a stall from a sideslipped condition was in the direction to cause the trailing wing to drop.

The small fixed wing-tip slots on one of the airplanes were found to have no measurable effect on its flying qualities or stalling characteristics.

INTRODUCTION

During the period beginning August 31, 1939 and ending July 27, 1940, the National Advisory Committee for Aeronautics conducted flying-qualities tests on five light airplanes. Data on the individual airplanes were not prepared in a form suitable for general release because of the urgency of military work which had begun at that time. The present paper gives a summary of data that has been compiled for the purpose of making available the findings of the NACA in regard to the stability and control characteristics of this type of aircraft.

The investigation comprised measurements of stability, controllability, and stalling characteristics. The results are based on data obtained from photographic records of continuously recording instruments supplemented by pilots' observations.

TESTS

Description of Airplanes

Descriptive characteristics of the five light airplanes are given in table I. Photographs of the five light airplanes are shown as figure 1 and three-view drawings are shown in figure 2. All five airplanes were two-place or three-place cabin land monoplanes and, except for airplane 2, all had fixed landing gears. Airplane 4 was the only one that had wing flaps and/or slots. The control-surface gaps were unsealed, except in the case of the rudder and elevator of airplane 2. The longitudinal trimming device consisted of an elevator trim tab for airplanes 1, 2, and 4; an adjustable stabilizer for airplane 3; and an independent airfoil mounted below the horizontal tail for airplane 5.

The gross weights and center-of-gravity positions for which the various airplanes were tested are as follows:

Airplane	Gross weight (lb)	Center-of-gravity position (percent M.A.C.)
1	1100	26.9
2	1503	22.0
3	975	25.1
4	1385	29.0
5	1060	24.4

The center-of-gravity positions given in this table are those approximately at the middle of the allowable center-of-gravity range and are those at which most of the tests were conducted. Other center-of-gravity positions were tested in connection with the effect of center of gravity and stalls. Some shift in center-of-gravity position occurred with fuel consumption.

Instrumentation

Continuous photographic records of control movements and the resulting motions and accelerations of each airplane were obtained by an installation of NACA recording instruments. The deflections of the three controls were registered by a three-component control-position recorder; the angular velocities in roll, yaw, and pitch, by three turnmeters; and the linear accelerations along the three axes of the airplane, by a three-component accelerometer. These records, together with those from a pressure recorder which measured airspeed and altitude change, were synchronized by means of a timer.

In addition to the recording instruments, an indicating yaw vane to assist the pilot in making specific maneuvers and a spring scale to measure the elevator control forces were used. The yaw vane, together with a calibrated sector, was mounted above the cabin where it could be read by the pilot.

The airspeed recorder was connected to a swiveling pitot-static head set a distance of 1 wing chord ahead of the leading edge of the wing at about the middle of the semispan. Both the airspeed recorder and the airspeed indicator were calibrated by means of a trailing airspeed head for airplanes 1 and 2, and the corrections derived for airplane 1 were assumed to apply to airplanes 3, 4, and 5 because of their similar configurations. The swiveling pitot-static head may be seen on the right wing in figures 1(a), 1(c), and 1(e) and on the left wing in figures 1(b) and 1(d).

In addition to the instrumentation previously described, airplane 2 was equipped with an indicating accelerometer and a sideslip-angle recorder. Airplane 4 carried a sideslip-angle recorder and a recording inclinometer as well as the standard instrumentation. The sideslip-angle recorder vanes may be seen mounted ahead of the right wing in figures 1(b) and 1(d).

Elevator angles are presented with reference to the thrust axis except for the case of airplane 4, for which the stabilizer is used as a reference. If elevator angles had been given with respect to the thrust axis for this airplane, all values of elevator angle would have been shifted upward 3°. The control-position recorders were located in the cockpit, and cable stretch may therefore have caused some error in control positions.

RESULTS AND DISCUSSION

This investigation covered longitudinal and maneuvering stability, landing characteristics, lateral stability and control, stalling and spinning characteristics, and the effect of slots on flying qualities. Further discussion of the effects of the measured stability and control parameters on the flying qualities and a set of quantitative requirements for satisfactory flying qualities will be found in reference 1.

Longitudinal Stability and Control Characteristics

Static longitudinal stability.- The static longitudinal stability characteristics of the five light airplanes for the power-on cruising condition at a center-of-gravity position in the middle of the allowable range are shown in figure 3. The trim devices were set at neutral for four of the five airplanes. No data on airplane 2 with tab neutral were available; therefore data with the airplane trimmed full nose heavy (tab 3° up) were used. It is not believed that this tab deflection would cause much variation in elevator angle and stick force from those with neutral tab position. This condition was chosen because it is the one in which the most flying time is spent and is the one for which the most comparable data were available. The variation of elevator angle with airspeed, shown in the lower part of figure 3, is an indication of the so-called stick-fixed static longitudinal stability and provides an indication of the stability in terms of the pilot's feel of stick position. Positive stick-fixed stability insures that the airplane will tend to return to a given angle of attack or airspeed following a disturbance. The five light airplanes tested were statically stable, longitudinally, with stick fixed and power on, as shown by the negative slope of the curve of elevator position against airspeed, although the degree of stability varied considerably among the five airplanes. The curves also show that, for each airplane, the up-elevator position required to stall with power on was low relative to the maximum deflection of the elevator. Desirable stall-warning characteristics would be represented by more rearward stick positions and larger stick forces at the stall.

The stick-free static longitudinal stability characteristics in the power-on cruising condition are shown by the curves of elevator stick force plotted against airspeed in the upper part of figure 3. The variation of elevator stick force with airspeed is an important criterion of the pilot's control "feel." The curves show that all five airplanes were statically stable, longitudinally, with stick free and power on and that the forces were small compared to the pilot's physical capabilities.

The friction in the control system is a factor that should also be included in any discussion of control forces. The force gradient experienced by the pilot with change in airspeed is highly influenced by the amount of friction that must be overcome. Friction in the system also reduces the ability of the airplane to return to its trim position when the stick is displaced and then released. Friction will prevent a pilot from obtaining a consistent "feel" for a given attitude in a given configuration and will make trimming the airplane more difficult. The tendency of the airplane to return to its trim airspeed when the stick is displaced and then released will be large if the slope of the force curve is large but will always be reduced if the friction is large. The friction in the elevator system of each of the airplanes tested was as follows:

Airplane	Friction (lb)
1	$8\frac{1}{2}$
2	1
3	4
4	Not determined
5	5

The control friction of airplanes 1, 3, and 5 was reported by the pilots to be excessive; on the other hand, that of airplane 2 was considered unusually, but favorably, low.

The effect of power on the static longitudinal stability is shown in figure 4 for airplanes 2 and 4. The stick-fixed static longitudinal stability of both airplanes was increased with power off, as shown by the steeper slope of the curve of elevator angle against airspeed. This effect was the same for all five airplanes tested. The increased pull forces required to trim at a given airspeed with power off may be seen from the curves of figure 4 for both airplanes although the force changes are greater for airplane 4. Had the airplanes been trimmed at the same airspeed for the power-off condition as for the power-on condition, the slopes of the power-off curves would have been increased and would indicate an increase in stick-free static longitudinal stability.

The effect of retracting the landing gear on static longitudinal stability is shown in figure 5 for airplane 2. No appreciable change in stability was obtained, stick-fixed or stick-free, but the up-elevator angles and pull forces required to trim at various airspeeds were reduced throughout the speed range by retracting the landing gear. This reduction of the angles and forces would be expected because of the nosing-down tendency resulting from the combination of the drag of the extended landing gear and the forward and downward movement of the center of gravity relative to the thrust axis.

The effect of flaps on the static longitudinal stability of airplane 4 is shown in figure 6. Deflecting the flaps caused a decrease in stability, both stick-fixed and stick-free, and also reduced the up-elevator angles and pull forces required to trim at various airspeeds throughout the speed range. These effects were probably caused by a change in downwash over the horizontal tail and/or a change in dynamic pressure at the tail with flaps down. Notice the slight stick-free instability and stick-fixed neutral stability which occurs in the power-on flaps-down condition at speeds above 60 miles per hour. This condition was the only one in which negative stability was found to exist for any of the airplanes tested.

The effect of center-of-gravity position on static longitudinal stability is shown in figure 7. A forward shift in center-of-gravity position resulted in an increase in stability, both stick-fixed and stick-free. The stick-force curves shown were obtained with a constant trim-tab setting, and as a result the trim speed was increased by the forward movement of the center of gravity. Figure 7 shows that approximately a constant increment of force was required to maintain trim at any speed when the center-of-gravity position was changed. If the airplane had been trimmed at the same airspeed in each case, the slope of the curves for the more forward center-of-gravity positions would have been increased and those for the more rearward center-of-gravity positions would have been decreased; thus the changes of stability with center-of-gravity position would have been more obvious.

The effect of the trimming-device setting on the variation of the force with speed for three of the airplanes tested is shown in figure 8. The adjustable stabilizer on airplane 3 and the elevator trim tab on airplane 4 were satisfactory for trimming the airplanes under all conditions. Although the curve for the tab nose-heavy condition of airplane 4 indicates little variation of stick force with speed, it does not indicate neutral stick-free stability because the airplane was not trimmed to zero stick force. It actually indicates that the tab is sufficiently powerful to trim the airplane at speeds much higher than the maximum level flight speed of the airplane at this particular center-of-gravity position, or at all speeds up to the maximum level-flight speed, at the most rearward center-of-gravity position. The trimming device on airplane 5 exhibited a lack of power, as shown in figure 8, and might be inadequate to trim at forward center-of-gravity positions. The trimming device on this airplane consisted of an independent airfoil mounted on the sides of the fuselage under the stabilizer instead of an elevator trailing-edge tab or adjustable stabilizer as used on the other airplanes tested. (See table I.)

Dynamic longitudinal stability.- The dynamic longitudinal stability characteristics were measured by recording the airspeed and the elevator position during control-free oscillations at various airspeeds and flight configurations. The oscillations were produced by releasing the elevator in steady flight at a speed greater than that for trim. A time history of a typical oscillation showing records of the airspeed and elevator position is given in figure 9 for airplane 4. Figure 10 shows the period and damping characteristics of two of the airplanes tested. All the airplanes tested were dynamically stable throughout most of the speed range, although airplanes 2 and 4 were dynamically unstable at low speeds as shown for airplane 2 in figure 10. The characteristics of this type of oscillation are shown by the tests of reference 2 to have no correlation with the ability of pilots to fly an airplane efficiently, the long period of the oscillation making the degree of damping unimportant. This conclusion has been substantiated by subsequent tests. The damping characteristics shown in figure 10 represent approximately the extreme conditions encountered in the tests of these five light airplanes.

Maneuvering stability.- Elevator effectiveness in maneuvers for all airplanes was measured by recording the normal accelerations and pitching velocities experienced in abrupt pull-ups and push-downs at various speeds. An indication of the effectiveness of the elevator at very low speeds, as, for example, in pitching out of the stall condition, is given by the push-down data obtained at very low speeds. Accelerated-flight data typical of that for all five airplanes is given for airplane 3 in table II. The pitching accelerations and displacements in pitch were obtained by differentiating and integrating, respectively, the angular velocity records. Elevator effectiveness for all five light airplanes tested was considered normally powerful in both pull-ups and push-downs, either with power on or power off.

The normal accelerations obtained with the control fully deflected in abrupt pull-ups and push-downs are plotted, again for airplane 3, as a function of airspeed in figure 11. It appears from this figure that the elevators of airplane 3 were capable of maneuvering the airplane to the design positive load factor (4.30g). The data were similar for all five airplanes tested.

An indication of stick-fixed maneuvering stability at speeds only slightly above the stall is given for airplane 1 in figure 12. The response to down elevator is shown to be entirely adequate with power off as well as with power on. This test was conducted for only airplane 1, but other maneuvering data indicate that the response of the other four airplanes to elevator control in push-downs should be similar to that of airplane 1.

Because of the difficulty in determining stick forces in accelerated flight with the spring scales then in use, no force data were obtained in pull-ups, push-downs, or turns. Qualitative calculations made for airplanes 1 and 2 show the stick force per g for airplane 1 to be approximately $2\frac{1}{2}$ times that of airplane 2. The main reason for this difference is the difference in elevator dimensions. The stick force per g is proportional to the product of the elevator span and the square of the root-mean-square chord, provided other factors remain constant. The two airplanes chosen for these calculations exhibited the extreme values of this product, the values being 16.36 and 6.16 cubic feet, for airplanes 1 and 2, respectively. Subsequent tests made by the Langley Flight Research Division on other airplanes have shown that values of stick-force gradients from 7 to 10 pounds per g are desirable for airplanes of this type.

Landing characteristics.- During these investigations, limited landing tests were conducted on airplanes 1, 2, and 5. The elevators of these airplanes were capable of producing three-point landings at forward center-of-gravity positions. The elevators of airplanes 1 and 5 produced three-point landings at deflections which were slightly less than the deflection required to stall the airplane at altitude with power off. Tail-low landings were made in airplane 2 at approximately the same elevator deflection as that required to stall at altitude.

Lateral Stability and Control Characteristics

Dynamic lateral stability.- Dynamic lateral stability characteristics were measured in power-on and power-off flight at various speeds above the stall. The tests consisted of trimming the airplane for straight flight insofar as possible, abruptly deflecting the rudder, and then releasing all controls. The period and damping of the oscillations were evaluated from the records of yawing velocity.

The yawing and rolling velocities as well as the sideslip angle resulting from a typical lateral oscillation are shown for airplane 4 in figure 13. The airplane may be seen to have exhibited a tendency toward spiral divergence as shown by the slight divergence of the yawing velocity at the end of the oscillation.

Data for period and damping of the lateral oscillations for two airplanes are plotted as a function of airspeed in figure 14. These data represent the extreme values of period obtained. The long period shown by airplane 5 indicates that this airplane had relatively low directional stability. In most cases the oscillations were heavily damped (to 1/2 amplitude in less than 0.6 cycles). In the case of airplane 2, however, the oscillations at higher speeds required about 1.5 cycles to damp to 1/2 amplitude. The damping was greater with power on for all airplanes except airplane 5 which showed better damping characteristics with power off than with power on. (See fig. 14.) Lateral oscillations were satisfactorily damped on all airplanes.

All airplanes exhibited spiral instability; that is, a tendency to diverge slowly into a spiral with the controls free, both with power on and with power off. Spiral instability is not considered objectionable, however, because tests have shown that this slow divergence does not detract from the pilot's ability to fly the airplane efficiently.

Sideslip characteristics.- The dihedral effect, the directional stability, the pitching moment due to sideslip, and the cross-wind force characteristics were measured by recording the control positions, angle of bank, and angles of sideslip in steady sideslips at various speeds. Data are presented for all five light airplanes in figures 15 to 19. Plots of elevator position, rudder position, aileron position, and angle of bank as a function of sideslip angle for power-on and power-off flight at both high and low airspeeds are presented. The effect of flaps is also shown for airplane 4 in figure 18. The sign and magnitude of the dihedral effect are indicated by the aileron used to counteract the rolling tendencies in the sideslip. The figures show the dihedral effect to have been relatively unaffected by power, to have been always positive since the aileron was always used to depress the leading wing, and to have been generally within desirable limits. The magnitude of the dihedral effect for airplane 2 (fig. 16) was comparatively small, only approximately 1.5° of aileron being used for a sideslip angle of 10°. Putting the flaps down on airplane 4 caused little change in the dihedral effect as may be seen in figure 18(a).

Directional stability is indicated by the sideslip produced for a given value of the wing-tip helix angle in rudder-fixed aileron rolls and by the variation of rudder angle with sideslip angle in steady sideslips. On the basis of the variation of rudder angle with sideslip angle, figures 15 to 19 show these five airplanes to have been directionally stable under all conditions to the limits of their respective rudder travel although considerable differences existed between the results for the different airplanes. The curves are everywhere continuous and fair with no reversals in slope even though angles of sideslip as high as 48° were reached in some cases. The pilots also reported smooth and continuous variations of rudder force. Greater sideslip angles were obtained in power-on flight for a given rudder deflection (from trim) than were obtained in power-off flight, the effect being more pronounced at low speed. Figure 20 shows a comparison of the relative directional stability characteristics, on the basis of the variation of rudder angle with sideslip angle, of two of the airplanes tested, airplanes 2 and 5. The greater directional stability of airplane 2 is immediately apparent, despite any difference in rudder effectiveness. The slopes of the curves show that considerably more rudder is required to produce a given amount of sideslip in airplane 2 than in airplane 5. However, as will be pointed out in the section "Rudder control characteristics," the rudder effectiveness of airplane 2 appears to be somewhat less than that of the other four airplanes despite the fact that the rudder hinge gap was sealed on this airplane. Reference to table I shows the product of tail length and total vertical tail area of airplane 2 to be approximately twice that of airplane 5, which fact would also indicate a greater directional stability of airplane 2. The low directional stability of airplane 5 in the power-on low-speed condition at low angles of sideslip is also apparent from figure 19. The low directional stability of airplane 5 resulted in an undesirably large amount of adverse yaw in rolling maneuvers, as will be discussed in the section "Aileron control characteristics." From figures 15 to 19 the directional stability of the other airplanes is seen to be between that of airplane 2 and airplane 5.

The relation between the angle of bank and angle of sideslip given in figures 15 to 19 shows that the cross-wind force of the five airplanes progressively increased with angle of sideslip and was of such magnitude that a reasonable amount of sideslip could be easily perceived by the pilot even at very low speeds. Because of the location of the wing tips relative to the pilot's vision in airplane 2, the pilots reported that, unless careful reference was made to the wing tips, it was easy to be banked 2° or 3° without being aware of it. Figure 18(a) shows that putting the flaps down on airplane 4 reduced the angle of bank slightly for a given sideslip angle.

The amount of elevator required for a given amount of sideslip is an indication of the pitching moment due to sideslip. The pitching moment due to sideslip is significant in that the magnitude may be of such a value as to cause an inadvertent stall. An airplane in which positive, or nose-up, pitching moment accompanies a sideslip would tend to stall as the sideslip is increased; on the other hand, an airplane in which the sideslip is accompanied by negative pitching moment would tend to stall when the sideslip is being reduced, as, for example, during recovery from an improperly coordinated turn. Figures 15 to 19 show that considerable differences in pitching-moment characteristics existed among these five airplanes although the change in pitching moment with sideslip was generally desirably small. In most cases the pitching moment was such as to cause the airplane to nose down at large sideslip angles although some airplanes which were in this classification also showed a tendency to nose up at small angles of sideslip. These two characteristics may be seen in figure 15 for airplane 1 in the power-on low-speed and power-off low-speed conditions, respectively. Airplane 4 in most cases tended to pitch up at large angles of sideslip, as may be seen in figure 18. Unsymmetrical pitching-moment characteristics are shown in figure 15 for airplane 1 in the power-off high-speed condition and in figure 19 for airplane 5 in the power-off low-speed condition. This type of characteristic is not particularly dangerous but is somewhat unusual in the power-off condition. The particular pitching-moment characteristic noted in the low-speed condition for a given configuration and airplane was generally encountered also at the higher speeds but the magnitudes were smaller. Airplane 2 showed little change in pitching moment with sideslip angle relative to that of the other airplanes, mainly because of the small sideslip angle attainable with this airplane. Because these tests were made by keeping the pilot's airspeed meter reading constant, these data are not entirely satisfactory, since considerable error was introduced in the airspeed system by sideslip on the pitot-static head. Partial stalling may have occurred during the low-speed power-off sideslips and may have introduced further error in the data.

Aileron control characteristics.- The aileron control characteristics of the light airplanes were investigated at various speeds in various flight configurations. Records were obtained of the rolling and yawing velocities and sideslip angles which resulted from abrupt deflections of the aileron control with the rudder held fixed.

Time histories of four representative aileron rolls are presented for airplane 4 in figure 21. The variation of rolling velocity, yawing velocity, angle of bank, and angle of sideslip with time when the ailerons are held over and the rudder is fixed are shown. Both the yawing velocity and sideslip angle may be seen to have been adverse in sign. All the airplanes exhibited adverse yaw although airplane 2 showed definitely less adverse yaw than the other four light airplanes. Airplane 2 was considered by the pilots to be a good two-control airplane because the adverse yaw for this airplane was not, under any conditions, objectionably large. As was pointed out in the section "Sideslip characteristics," the amount of sideslip produced in a rudder-fixed aileron roll may be considered as an indication of the directional stability of an airplane. Airplanes which show the most adverse yaw (sideslip angle) are considered to have low directional stability. The adverse yaw was particularly objectionable at low speeds in airplanes 4 and 5, as may be seen in figure 22, which shows time histories of aileron rolls at low speed with ailerons fully deflected for airplanes 3, 4, and 5. The maximum rate of roll in a roll with rudder fixed may be seen to have been sustained for only a short time and decreased rapidly because of the adverse sideslip and yawing which developed. It is believed that a larger fin area and/or a modified aileron design to reduce adverse yaw would produce a marked improvement in the flying qualities of airplanes 4 and 5. The time history shows that, although the rolling velocity for airplane 3 also decreased, the sideslip angles developed were not so large as those for the other two airplanes shown.

Rolling and yawing velocities and accelerations are presented as a function of the percentage of total aileron movement in figure 23 for airplane 4, which exhibited values of rolling velocities that approximated the values of those of the five light airplanes. The data so presented were taken from time histories of aileron rolls such as those of figures 21 and 22. The aileron effectiveness progressively increased with control deflection at all speeds for all five airplanes, and the magnitudes of the rolling velocities experienced for these airplanes were considered adequate by the pilots. Typical values of the rolling velocity and wing-tip helix angle for the five airplanes are given for various speeds and flight configurations at approximately full aileron deflection in table III. The helix angle is expressed by $\frac{pb}{2V}$, where p is the rolling velocity in radians per second, b is the wing span, and V is the forward velocity of the airplane in feet per second.

Only one of the values of $\frac{pb}{2V}$ given failed to exceed the minimum satisfactory value of 0.07 radian specified in reference 1.

The magnitudes of the rolling accelerations shown in figure 23 are of interest mainly from structural considerations, although the ratio of the rolling acceleration to yawing acceleration is of interest as a measure of the adverse yaw. Changes in power or flap condition for airplane 4 are seen from figure 23 to have no appreciable effect on the aileron characteristics. Likewise, landing-gear position had a negligible effect on the aileron characteristics of airplane 2.

Rudder control characteristics.- The rudder control characteristics were determined by abruptly deflecting the rudder various amounts in various flight configurations and recording the resulting motions of the airplane. These tests were repeated for several different speeds. The rudder effectiveness, measured by the displacements, velocities, and accelerations in yaw, is shown for airplane 1 in figure 24. The accompanying displacements and accelerations in roll are also given. The effectiveness of the rudder may be seen to have increased progressively with rudder deflection and to have been appreciably greater with power on than with power off, the difference for power-off low-speed flight being of the order of 50 percent of the power-on values. Similar characteristics were observed for airplanes 3, 4, and 5. The rudder effectiveness of airplane 2 in terms of yawing acceleration per degree of rudder deflection was smaller than for the other airplanes but was still adequate for all normal maneuvers. Extending the flaps on airplane 4 had the same effect on rudder effectiveness as "cutting" the power. The resulting reduction of rudder effectiveness was of the order of 50 percent.

The rudder-kick maneuvers shown in figure 24 for airplane 1 indicated a positive dihedral effect in all conditions, as did the sideslip tests, the displacements in roll and rolling accelerations always being to the right for right rudder deflections. The magnitude of the roll due to rudder was in no condition considered to be excessive by the pilot. This conclusion was reached for all airplanes where roll due to rudder was measured.

The effect of power on the rudder position required for straight unyawed flight is shown for airplane 1 in figure 25. As would be expected, the difference between rudder positions with power on and power off increased as the speed was reduced. The difference was 6° at 40 miles per hour. The effect of power on rudder position required for straight unyawed flight in the other four light airplanes was shown, where tested, to be similar to but of smaller magnitude than that of airplane 1. The difference in rudder angles was generally of the order of 4°.

The demands on the rudder in overcoming aileron yaw was shown by a comparison of the yawing accelerations produced by the ailerons and by the rudder when used separately. Although the aileron control characteristics (fig. 23) and the rudder control characteristics (fig. 24) are not given for the same airplane in this paper, a comparison of yawing accelerations obtained from similar data for a given airplane would indicate the power of the rudder in overcoming aileron yaw. Comparison of these data for all airplanes except airplane 3, for which the data were unavailable, showed the rudder to be sufficiently powerful to overcome aileron yaw at all speeds tested with power on and power off, although at low speeds with power off, a large amount of rudder deflection was required.

Stalling Characteristics

The stalling characteristics of the five light airplanes were studied by recording the movements of the controls and the resulting motions of the airplane produced in stalls from straight flight and from turning flight in various flight configurations. Tests were also made in airplane 3 of stalls which were entered with various amounts of sideslip. The stall data (figs. 26 to 43) are presented in the form of time histories, except figures 35 and 36 which are summary curves of characteristics determined from time histories of stalls produced in various conditions. A brief analysis of the records is included in the legend for each figure.

Stalls from straight flight.- Stalls from straight flight were produced with power on and power off at various center-of-gravity positions. No stall tests were made in airplane 2 with landing gear down; however, stalls in airplane 4 were made in both flaps-up and flaps-down conditions. Entry to the stalled condition was usually made by a gradual reduction in airspeed with the wings laterally level and with no intentional sideslip or skid.

To an experienced pilot, the stalls were generally well forewarned by light buffeting and preliminary motions in pitch, yaw, and roll which served as an indication that the more violent instability associated with the complete stall was imminent. The exception was airplane 4 in the power-on flaps-up and power-on flaps-down conditions. In these conditions no appreciable buffeting occurred with this airplane, but, as the stall was more closely approached, motions in pitch, yaw, and roll occurred which so increased in magnitude up to the complete stall that they were considered objectionable. Other stall warnings were the rapidly increasing stick forces and rearward movements of the control required in the approach to the stalling angle of attack with power-off and the steep nose-up attitudes reached with power on.

In all cases, for all flight configurations within the center-of-gravity limits tested, the usual lateral instability occurred when the complete stall was produced. This lateral instability took the form of a rapidly diverging oscillation which could not be controlled by means of the ailerons, although some measure of lateral control could be obtained by skillful use of the rudder. The maximum values of rolling velocity obtained in the rolling oscillations were similar for all the airplanes and were somewhat larger when larger up-elevator angles were used. The instability could be immediately checked at anytime by the slight application of down elevator. These characteristics are shown graphically by means of time histories of various stalls (figs. 26 to 34). A brief description of the characteristics portrayed is included in the legend for each figure. Comparisons of the characteristics of the different airplanes in stalls are given in table IV.

The development of instability in a slowly produced laterally level power-on stall in airplane 1, in which full-up elevator was not used, is shown in figure 26. Figure 27 shows a similar stall for airplane 2 in which full-up elevator was used. Response to the aileron in the stall is shown for airplane 5 in figure 28. All five airplanes showed about the same correct initial response to the ailerons followed by reversal of effectiveness as adverse yaw predominated. The response to the rudder with the stick all the way back in the stall is shown for airplane 4 in the flaps-up power-on condition in figure 29.

The development of instability in a slowly produced laterally level power-off stall in airplane 5 in which full-up elevator was not used is shown in figure 30. Similar stalls in other airplanes produced similar time histories. Figure 31 shows a time history of a similar stall in airplane 2 with a rearward center-of-gravity position during which a "falling-leaf" motion developed. A power-off stall from straight laterally level flight in airplane 2 with a forward center-of-gravity position in which full-up elevator was used is shown in figure 32. The response to the ailerons during a power-off stall in airplane 5 is shown in figure 33. The response to the rudder during a power-off stall in airplane 1 is shown in figure 34. Response to the rudder was correct but slow on all airplanes. The stalled wings exhibited a strong dihedral effect as shown by the rolling velocity following the rudder deflections.

The manner in which the stall developed in airplane 2 proved to be of interest. Tufts were therefore installed on the wings of this airplane and motion pictures were made of their action during a number of stalls. The description of a typical power-off stall in airplane 2 follows. The stall began at the trailing edge of the wing near the fuselage, progressed outward along most of the aileron, and then moved forward in a chordwise direction. When the right wing had become completely stalled, the airplane rolled and slipped to the right with the consequent unstalling of the wing. The regain in lift progressed rearward toward the trailing edge. When the right wing had become nearly unstalled, the left wing stalled, and the airplane rolled and slipped to the left. This alternate stalling and unstalling of each wing continued until relief was obtained by use of the elevators. It was difficult to determine from the motion-picture records whether the wing tip stalled in every case. When the tip stall was definitely observed, however, the tip was the last part of the wing to stall. This type of stall progression is of unusual interest in view of the 2:1 taper ratio of the wing of this airplane.

During these tests, both airplanes 1 and 5 were made stallproof in the power-off condition by limiting the up-elevator travel to an angle slightly less than the angle at which lateral instability occurred. Normal three-point landings were performed with the elevator limited in this manner, and the control was sufficient to allow such power-off turns and maneuvers as the pilot felt would ever be required. It is of further interest that violent applications of the rudder with the stick completely back did not produce the stall. Elimination of the stall with power on as well as with power off would, of course, require approximately the same elevator angle for stall with full power as with engine idling; therefore the limit applied to the up-elevator travel would be below the elevator angle required to stall in either power condition. An investigation is described in reference 3 in which the effect of power on the elevator angle required to stall was reduced considerably in an effort to make the subject airplane stallproof. The tests described in reference 3 were made with an airplane of the same type as airplane 3 and were made as a result of some of the findings reported herein. Although this airplane was not made completely stallproof in all conditions, it was made spinproof.

The effect of power on the elevator angle required to stall at different center-of-gravity positions is shown in figure 35 for airplanes 2 and 3. Airplane 2 showed the least effect of power on the elevator angles at which motions not initiated by the pilot first occurred, and airplane 3 showed the most effect of power of all the airplanes tested. The difference between elevator angles for the power-on and power-off conditions was of the order of 6° for airplane 2 and 13° for airplane 3 as shown in figure 35. Figure 35 also shows the effect of longitudinal trim for airplane 3 and landing-gear position for airplane 2.

Stalls from turning flight.- Stalls from turning flight were produced or attempted at various speeds (by varying the tightness of the turn) with power on and power off. Summary curves of the normal acceleration, elevator angle, and pitching velocity at which lateral instability occurred are shown as a function of airspeed for airplane 1 in figure 36. Time histories showing the characteristics of the airplanes in stalls from turns are shown in figures 37 to 40. A brief description of each stall is included in the legend for each figure. Comparison of the characteristics of the different airplanes in stalls from turns is given in table IV. No data on stalls in turns were obtained for airplane 2.

The instability associated with the complete stall was essentially the same in turning flight as in straight flight. The violence of all motions accompanying the stall was increased somewhat in turning flight because of the effectively increased wing loading under accelerated conditions. The preliminary motions about all three axes became an unmistakable stall warning. Stall warnings for all airplanes tested were the increased rearward stick positions and the increased elevator forces required to produce a stall in turning flight. Figure 36 shows that the elevator angle required to stall in airplane 1 increased almost linearly with the indicated stalling speed in the turn. The increase in up-elevator position was required to produce the pitching velocity in the turn. This increase in elevator angle required was so great in power-off turns that full-up elevator would not produce the stall at speeds above 56 miles per hour. This characteristic was approximately the same for the other airplanes tested. The airspeed above which the airplane could not be stalled in turns with power off varied with airplanes because of their different characteristics and the difference in up-elevator travel limits. The increase of elevator angle required to stall in power-on turns over that required in straight flight was of similar magnitude for airplanes 1, 3, and 5, but because the elevator angle required to stall in straight flight was lower with power on than with power off, stalling in turns with power on was possible at all speeds tested. Airplane 4 could not be stalled in tight turns even with power on. In shallow turns to the left, however, it was possible by certain definite control action to spin this airplane in the direction of the turn.

The lateral instability in stalls from turns was similar to that in stalls from straight flight and generally occurred as a rapidly diverging oscillation from which recovery was easily made by pushing the elevator control forward. A detailed description of some of the individual characteristics is given as follows:

A time history of a stall from a tight power-on left turn is shown in figure 37 for airplane 5. This figure shows that the airplane rolled out of the left turn when sideslip was carried. A power-on right turn in which the airplane again rolled out of the turn when sideslip was carried is shown in figure 38 for airplane 3. This characteristic was also quite typical of airplanes 1 and 5 in this condition. The initial roll-off was found to be either into or out of the turn, the direction depending on whether the airplane carried skid or sideslip, respectively. All the turns in airplanes 1 and 3 carried sideslip, as indicated by the transverse acceleration (plotted positive for acceleration to the left), and the downwind wing stalled first in every case so that the direction of initial roll-off was always out of the turn. When neither sideslipping nor skidding was present, airplane 5 tended, in most cases, to roll into the turn when instability occurred. Instability in this direction is considered a particularly dangerous condition because of the resulting attitude which makes recovery an acrobatic maneuver requiring considerable altitude.

A time history of an attempt to stall airplane 3 in a power-off left turn is shown in figure 39. Airplane 5 stalled in a power-off right turn as shown in figure 40.

<u>Stalls from steady yawed flight</u>.- Stalls from steady yawed flight were produced in airplane 3 to compare the resulting stalling characteristics with those experienced under unyawed conditions with particular regard to studying the effects of carrying sideslip or skid in turning flight. These stalls were executed by the usual gradual reduction in airspeed, but the rudder and ailerons were manipulated to maintain a steady yawed condition. The direction of roll-off and the violence of the resulting instability were studied. The results are presented in the form of time histories in figures 41 to 43.

In stalls carrying initial sideslip the relation between the up-elevator angle and the angle of attack for lateral instability changed from that which existed for straight unyawed flight so that greater amounts of up-elevator angle or more rearward positions of the stick were required to stall in every case. In the power-on conditions, the change in pitching moment produced by sideslip was not sufficient to prevent the complete stall. In these stalls the instability was increased in violence because the control disposition required for the sideslip carried corresponded to that used in spinning. The sequence of events when instability developed was a dropping of the downwind wing and a rapid turning toward the dropping wing because of the increased drag of that side as well as the sudden loss of equilibrium between the angle of bank and the cross-wind force. In every case the roll occurred in the direction opposite to the sideslip. These characteristics are shown in figures 41 and 42. In power-off conditions, sideslip angles of 20° so limited the effectiveness of the elevator that complete stalls could not be produced with the stick full back, as shown in figure 43; although with 10° sideslip, rolling instability could be produced.

It is therefore obvious that stalling with crossed controls is likely to lead to instability of increased violence and may be particularly serious, as mentioned before, if it is produced with skid in a turn because of the resulting attitudes of the airplane. Manipulation of the yaw-producing control may therefore markedly decrease safety in flight when the airplane is operated by inexperienced personnel.

Spinning Characteristics

Spin tests were conducted on airplane 4 to determine the combination of flap and control positions and power which would produce a spin. No spin investigations were made with the other airplanes. A spin was produced in airplane 4 only under the following conditions:

(a) Power on full

(b) Flaps up or down

(c) Left rudder in a shallow left turn

(d) Elevator full back

(e) Ailerons against roll as the wing dropped into turn

Recovery was rapid and automatic when the power was reduced or the controls were neutralized. A typical time history of a spin and recovery is shown in figure 44. All attempts to spin from other conditions resulted in spirals.

Effect of Slots on Flying Qualities

Comparable test maneuvers to determine the effect of the wing-tip slots of airplane 4 on the flying qualities of the airplane were performed with the slots open and closed. For the slots-closed tests the slots were covered and faired by a thin sheet of metal.

The characteristics specifically investigated were stalling, aileron effectiveness at speeds close to the stall, and longitudinal stability. Figure 45 presents comparable aileron-effectiveness data for both slotted and unslotted conditions. It will be noted that the slots had no measurable effect. Data on the longitudinal stability also showed an inconsequential effect. Although actual records are too lengthy to include, no measurable effect of the slots on stalling characteristics was discernible either to the pilot or through analysis of the data. The spinning data also remained unchanged.

CONCLUSIONS

Flight tests of five light airplanes have defined their flying qualities in terms of certain quantitative data obtained in various maneuvers and flight conditons. Comparison of the characteristics of these airplanes with the standard requirements for satisfactory flying qualities leads to the following conclusions:

1. All the airplanes tested showed stability of the long-period longitudinal oscillation except two of the airplanes which were unstable at low speeds. Dynamic longitudinal stability of these airplanes was not considered a significant factor, however.

2. The static longitudinal stability, indicated by the variation of elevator position and force with airspeed, was positive for all airplanes and at all conditions tested except for a slight instability in the power-on flaps-down condition for one of the airplanes at airspeeds exceeding 60 miles per hour. The degree of stability varied considerably among the five airplanes, but the up-elevator position required to stall with power on was low relative to the maximum deflection of the elevator. Control friction, which had the effect of masking the true control forces, was considered to be excessive in several of the airplanes tested.

3. The elevators of all airplanes tested appeared to be capable of developing the positive limit load factor of the airplane and were capable of producing three-point landings at a forward center-of-gravity position and of producing sufficiently rapid recovery from a stall.

4. Lateral oscillations were satisfactorily damped on all airplanes.

5. The ailerons of all airplanes tested produced rolling velocities which varied smoothly with aileron deflection and which were approximately proportional to aileron deflection. The maximum rolling velocity obtained by use of the ailerons was such that the helix angle generated by the wing tip equalled and in some cases greatly exceeded the value of 0.07 radian established as a minimum for satisfactory aileron control.

6. Wide variations in directional stability were encountered among the five airplanes. The adverse yaw was considered objectionable on the airplanes which had low directional stability.

7. The dihedral effect was positive and generally within desirable limits for all the airplanes tested. The bank accompanying sideslip was desirably large even at low speeds for all airplanes.

8. The rudders of all airplanes for which data were available were sufficiently powerful to overcome adverse yaw and to trim the airplane in straight flight.

9. The pitching moment due to sideslip was generally desirably small at small angles of sideslip. On several of the airplanes an appreciable nosing-down tendency was measured at large sideslip angles.

10. Stall warnings were considered good for all five airplanes, although the ensuing instability which consisted of a rapidly increasing rolling and yawing oscillation at the complete stall was considered objectionable. The stall warning in general consisted of buffeting, increased stick force, and rearward stick travel, although these last two characteristics were rather small with power on. The ailerons were ineffective in maintaining lateral control in a power-on stall in any of the airplanes. Recovery from the stalled condition was easily made on all airplanes by pushing the elevator control forward.

11. Stalls from steady turning flight were possible in the power-on condition in three of the four airplanes tested, although stalls from turning flight with power off were generally impossible above a certain flying speed because sufficient elevator control was not available. The motion of the airplane following a stall from a turn was usually more violent than that from straight flight. The initial roll-off in a stall from a sideslipped condition was in the direction to cause the downwind wing to drop.

12. The small fixed wing-tip slots on one of the airplanes were found to have no measurable effect on its flying qualities or stalling characteristics.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., November 25, 1947

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2. Soulé, Hartley A.: Flight Measurements of the Dynamic Longitudinal Stability of Several Airplanes and a Correlation of the Measurements with Pilots' Observations of Handling Characteristics. NACA Rep. No. 578, 1936.

3. Hunter, P. A., and Vensel, J. R.: A Flight Investigation to Increase the Safety of a Light Airplane. NACA TN No. 1203, 1947.

TABLE I

DIMENSIONAL CHARACTERISTICS OF TEST AIRPLANES

Item	Airplane 1	Airplane 2	Airplane 3	Airplane 4	Airplane 5
Wing type	High strut-braced	Low cantilever	High strut-braced	High strut-braced	High strut-braced
Landing gear	Fixed	Retractable	Fixed	Fixed	Fixed
Engine	4 cylinder horizontally opposed	5 cylinder radial	4 cylinder horizontally opposed	4 cylinder horizontally opposed	4 cylinder horizontally opposed
Rated power, hp at rpm	65/2450	90/2250	50/2300	80/2700	65/2450
Normal gross weight, lb	1150	1700	1100	1580	1050
Propeller diam. and pitch, in.	72, 44	74, 58	70, 45	70, 42	72, 44
Number of blades	2	2	2	2	2
Wing loading, lb/sq ft	6.8	10.5	6.17	10.2	5.84
Power loading, lb/hp	17.7	18.9	22.0	19.75	16.15
Wing airfoil section	Clark Y	Bellanca B	USA 35-B (Modified)	NACA 4412	NACA 23012
Wing plan form	Rectangular with rounded tips	Tapered 2:1 with angular tips	Rectangular with rounded tips	Rectangular with rounded tips	Rectangular with rounded tips
Wing area including fuselage area, sq ft	169	161.5	178.5	155	180
Wing span, ft	36.0	34.16	35.21	34.00	36.00
Mean aerodynamic chord, ft	4.68	4.95	5.14	4.59	4.98
Aspect ratio	7.65	7.22	6.94	7.46	7.20
Dihedral, deg	1.5	4.5	1.0	2.5	1.0
Wing incidence, deg	-1.5	-1.0 (approx.)	1.8	-0.6	3.8
Washout, deg	----------	--------	3.0	1.5	3.5 (approx.)
Flap type	None	None	None	Slotted	None
Flap area, sq ft	----------	--------	----------	12.2	----------
Max. flap deflection, deg	----------	--------	----------	31	----------
Total wing-slot length, percent wing span	0	0	0	19.4	0
Aileron type	Frise	Frise	Frise	Frise	Frise
Aileron area (each), sq ft	9.9	7.0	9.6	9.0	8.7
Aileron deflection, deg	±27.5	±22.5	±19	-14 to 28	±22
Aileron span, percent wing semispan	38.4	50.2	48.4	44.0	44.0
Aileron moment arm, percent wing semispan[a]	65.3	71.7	61.9	68.8	73.7
Horizontal tail length, ft[b]	14.83 (approx.)	15.40	15.50	14.96 (approx.)	15.58 (approx.)
Stabilizer area, sq ft	13.66	15.67	14.65	14.20	15.00
Stabilizer incidence, deg	-5	-2 (approx.)	-5 to 1.5	-3	0
Horizontal tail span, ft	10.16	10.81	9.50	9.33	10.00
Max. stabilizer chord, in.	23.69	22.80	26.81	29.75	26.88
Elevator area, sq ft	11.54	9.49	10.64	10.75	10.80
Elevator deflection, deg	33 up, 33 down	23 up, 20 down	36 up, 28 down	27.5 up, 26 down	27 up, 27 down
Elevator type	Plain flap	Plain flap, sealed gap	Plain flap	Plain flap	Plain flap
Longitudinal trimming device	Adjustable tab	Adjustable tab	Adjustable stabilizer	Adjustable tab	Adjustable independent airfoil
Trimming device area, sq ft	0.38	1.16	14.65	0.77	----------
Trimming device deflection, deg	25 up, 25 down	3 up, 22 down	1.5 up, 5 down	15.5 up, 30 down	38 up, 33 down
Elevator span times mean chord squared, cu ft	16.36	6.16	14.73	10.54	12.60
Vertical tail length, ft[c]	15.33 (approx.)	15.82	15.88	13.96 (approx.)	15.91 (approx.)
Fin area, sq ft	6.50	[d]10.97 (total)	4.02	8.41	3.50
Rudder area, sq ft	8.20	6.28	[e]6.55	[e]6.76	6.20
Rudder deflection, deg	±30	±15	±33	±16	±26
Type rudder	Plain flap	Plain flap, sealed gap	Horn balanced	Horn and overhang balanced	Plain flap
Balance area, percent rudder area	0	0	13.8	12.7	0
Directional trimming device	None	None	None	None	Small fixed tab
Type of cockpit control	Wheel	Stick	Stick	Wheel	Wheel

[a]Midspan aileron to center line of airplane.
[b]Leading edge of root chord to elevator hinge line.
[c]Leading edge of root chord to rudder hinge line.
[d]Three fins; outboard fins 2.65 square feet each.
[e]Includes balance area.

TABLE II

PULL-UPS AND PUSH-DOWNS, AIRPLANE 3

Power	Correct indicated airspeed (mph)	Max. elevator angle (deg)	Max. normal acceleration (g)	Max. pitching velocity (radians/sec)	Max. pitching acceleration (radians/sec^2)	Pitch displacement in $\frac{1}{3}$ sec (deg)
Pull-ups						
On	44	36 up	1.80	1.17	6.04	8.1
	53	36 up	2.35	1.33	6.90	11.3
	60	36 up	2.90	1.42	6.90	9.5
	62	36 up	2.75	1.40	6.90	9.3
	73	36 up	3.55	1.54	8.02	11.5
	74	36 up	3.77	1.62	7.35	11.1
	74	36 up	2.85	1.60	8.16	----
Off	44	36 up	1.50	0.67	4.72	4.2
	53	36 up	2.07	1.00	5.50	6.9
	62	36 up	2.78	1.25	7.35	7.6
	74	36 up	3.77	1.46	6.90	----
Push-downs						
On	33	28 down	0.16	-0.58	3.19	4.0
	43	28 down	.16	-.52	2.30	4.2
	57	28 down	-.21	-.45	2.47	4.7
	74	21 down	-.07	-.30	2.53	5.2
Off	39	28 down	0.16	-0.45	2.21	3.7
	46	28 down	0	-.45	2.77	4.5
	63	28 down	-.10	-.38	2.36	3.5
	74	24 down	-.30	-.36	3.04	5.5

TABLE III

VALUES OF ROLLING VELOCITY AND WING-TIP HELIX ANGLE FOR FIVE LIGHT AIRPLANES

Configuration	Correct indicated airspeed (mph)	Rolling velocity (radians/sec)	Wing-tip helix angle
Airplane 1			
Power off	90	1.12	0.153
Power on	90	1.08	.147
Power off	60	.78	.160
Power on	60	.71	.145
Power off	37	.51	.168
Power on	30	.47	.192
Airplane 2			
Power off	97	0.77	0.093
Power on, wheels down	97	.83	.100
Power off	56	.35	.073
Power on, wheels down	53	.31	.068
Airplane 3			
Power off	80	0.69	0.103
Power on	80	.65	.097
Power off	60	.56	.112
Power on	60	.54	.108
Power off	35	.33	.113
Power on	30	.28	.112
Airplane 4			
Flaps up	80	0.80	0.116
Flaps up	50	.46	.106
Power on	45	.40	.103
Power on, flaps down	40	.33	.095
Airplane 5			
Power off	75	0.63	0.103
Power on	75	.64	.105
Power on	62	.53	.105
Power off	58	.51	.108
Power off	40	.31	.095
Power on	37	.30	.099

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TABLE IV

STALLING CHARACTERISTICS

[Comparison of values refers to values given in the figure for any given flight condition.]

	Airplane 1	Airplane 2	Airplane 3	Airplane 4	Airplane 5
Slowly developed power-on stall, less than full-up elevator	See figure 26	Angular velocity less than 0.2 radians/sec; airspeed and acceleration oscillation of same period as airplane 1	- - - - - - - - - - - - -	Flaps up: angular velocity reached -0.3 radians/sec in 3rd cycle of diverging long-period oscillation; airspeed oscillation twice magnitude of that of airplane 1. Flaps down: no oscillation, diverged into high-speed spiral	Angular velocity less than 0.2 radians/sec; airspeed and acceleration oscillation same period as that of airplane 1
Power-on stall, full-up elevator	- - - - - - - - - - - - -	See figure 27	- - - - - - - - - - - - -	Flaps up; small amplitude oscillation about all 3 axes which tended to damp out	- - - - - - - - - - - - -
Response to aileron, power-on	Correct initial response; reversal of effectiveness as aileron yaw predominated; angular velocity slightly higher; full-up elevator	Correct initial response, reversal of effectiveness as aileron yaw predominated; angular velocity smaller	Correct initial response, reversal of effectiveness as aileron yaw predominated; angular velocity about same as for airplane 5	Correct initial response, reversal of effectiveness as aileron yaw predominated; full-up elevator but angular velocity about same as for airplane 5	See figure 28
Response to rudder, power-on, full-up elevator	- - - - - - - - - - - - -	Response similar, loss of control following use of large rudder deflections more prompt, less extreme than airplane 4	Same as airplane 2	See figure 29; flaps up	- - - - - - - - - - - - -
Slowly developed power-off stall, less than full-up elevator	Motions about same, airspeed oscillation tended to diverge	Motions much smaller, amplitude of airspeed oscillation of order of 1 mph	- - - - - - - - - - - - -	Motions much smaller	See figure 30
Slowly developed power-off stall, less than full-up elevator, rearward c.g. position	- - - - - - - - - - - - -	See figure 31; "falling leaf"	- - - - - - - - - - - - -	- - - - - - - - - - - - -	- - - - - - - - - - - - -

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TABLE IV – Concluded

STALLING CHARACTERISTICS – Concluded

	Airplane 1	Airplane 2	Airplane 3	Airplane 4	Airplane 5
Power-off stall, full-up elevator	Rapidly increasing airspeed and steep glide path indicating flight beyond $C_{L_{max}}$; large rolling and pitching motions; rate of descent about 1500 ft/min	See figure 32	-------------	-------------	Motions prevented by juggling rudder; use of ailerons resulted in loss of control manifested by large rolling and yawing velocities; airspeed oscillations erratic, diverged when control was lost
Response to ailerons, power off	Correct initial response, but rolled against ailerons as aileron yaw predominated	Correct initial response, but rolled against ailerons as aileron yaw predominated; aileron yaw not as strong as on other airplanes	Same as airplane 1	Correct initial response, but rolled against ailerons as aileron yaw predominated; aileron yaw not as strong as on airplanes 1, 3, and 5	See figure 33; aileron yaw stronger than on other airplanes
Response to rudder, power off	See figure 34	Response correct but slow; strong dihedral effect	Same as airplane 2	Same as airplane 2	Same as airplane 2
Stall from power-on tight left turn	Larger values of maximum rolling velocity; longitudinal instability more prevalent	-------------	Larger values of maximum rolling velocity	Could not be stalled	See figure 37; very few preliminary motions
Stall from power-on right turn	Similar to figure 38	-------------	See figure 38	-------------	Similar to figure 38
Stall from power-off left turn	Could not be stalled	-------------	See figure 39; could not be stalled	-------------	Stalled and rolled into turn although no slipping was present
Stall from power-off right turn	-------------	-------------	Did not stall; controlled aileron rolls made to right and left; pitching oscillations indicated stall was imminent	-------------	See figure 40; very few preliminary motions

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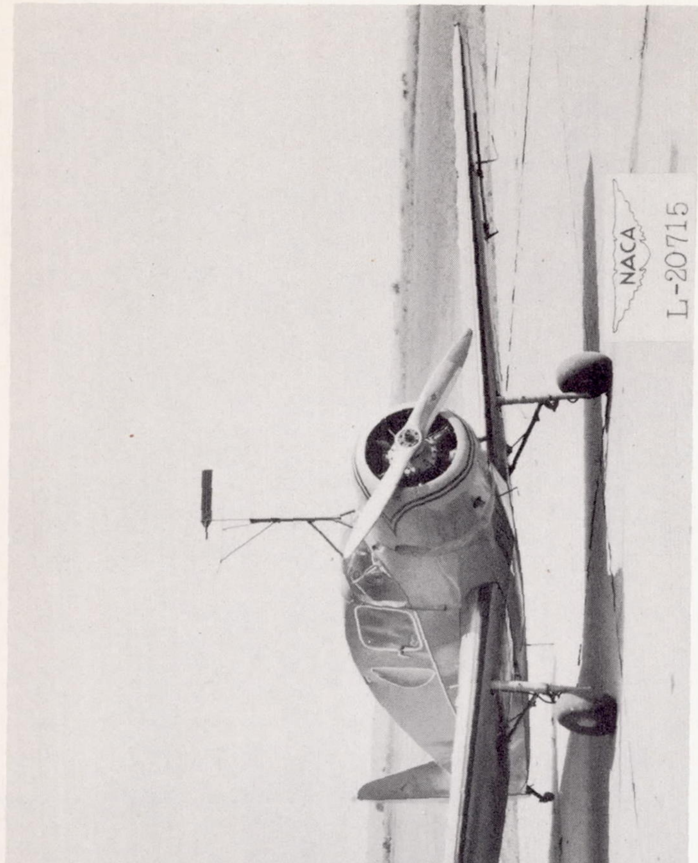
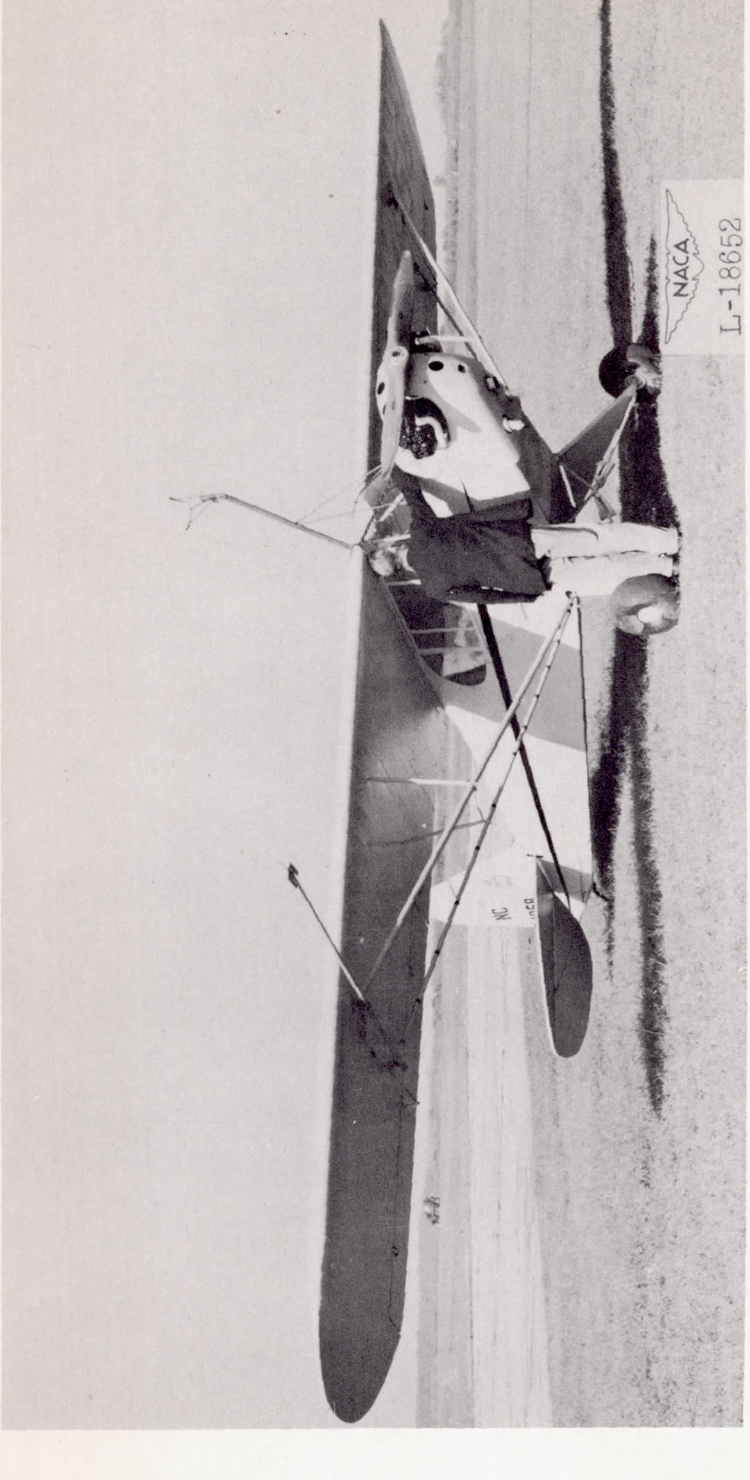
(a) Airplane 1.

Figure 1.- Three-quarter front views of airplanes tested.



(b) Airplane 2.

Figure 1.- Continued.

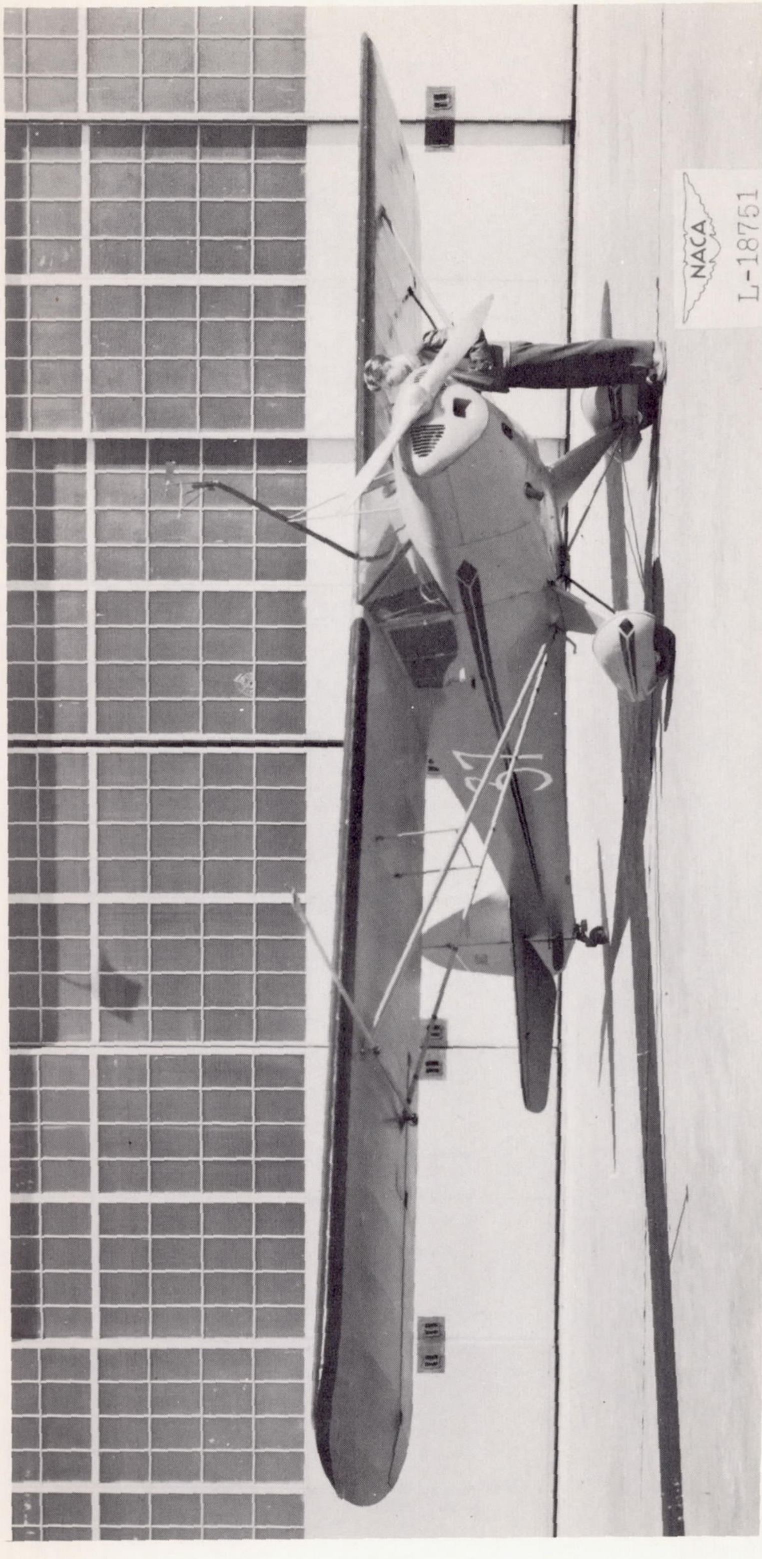


(c) Airplane 3.

Figure 1.- Continued.

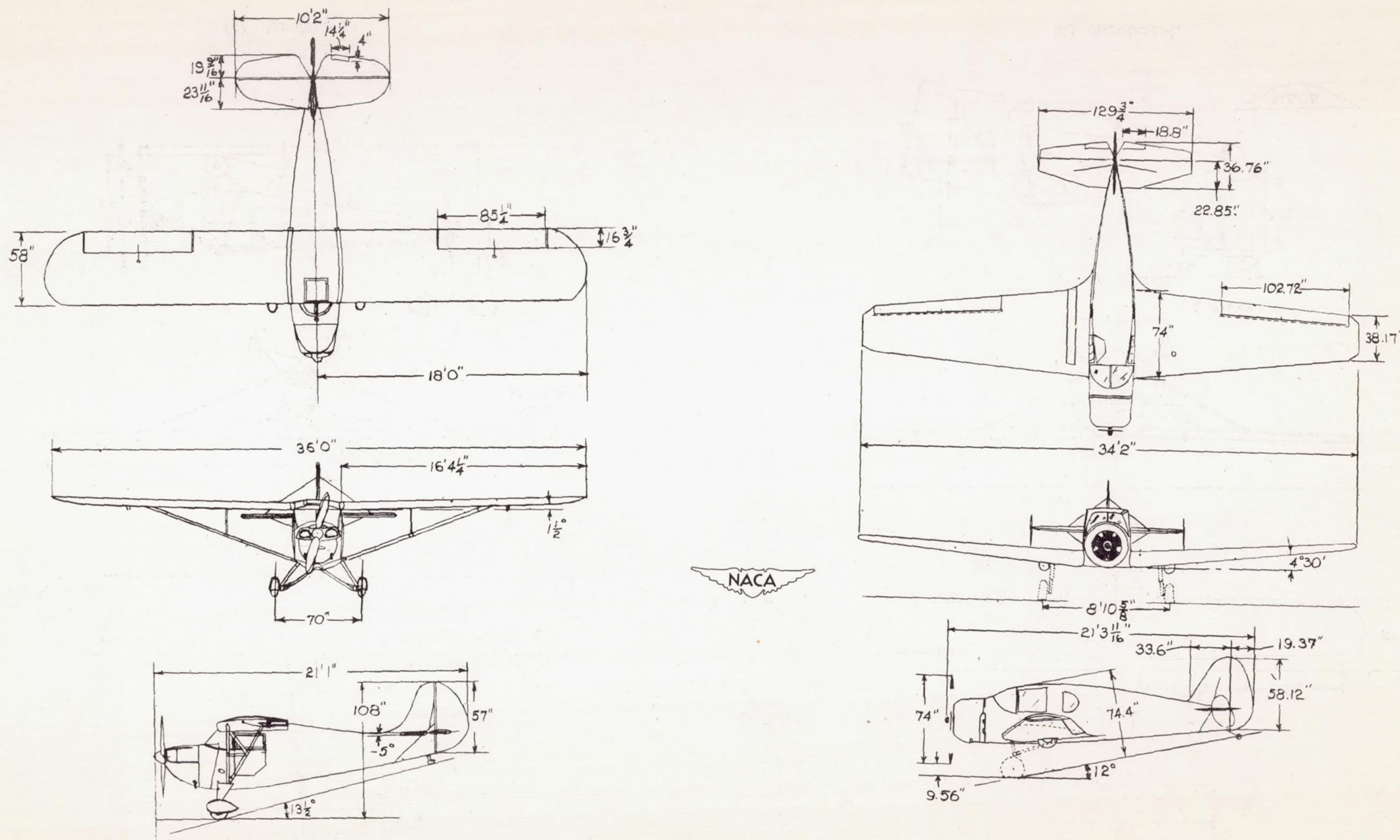
(d) Airplane 4.

Figure 1.- Continued.



(e) Airplane 5.

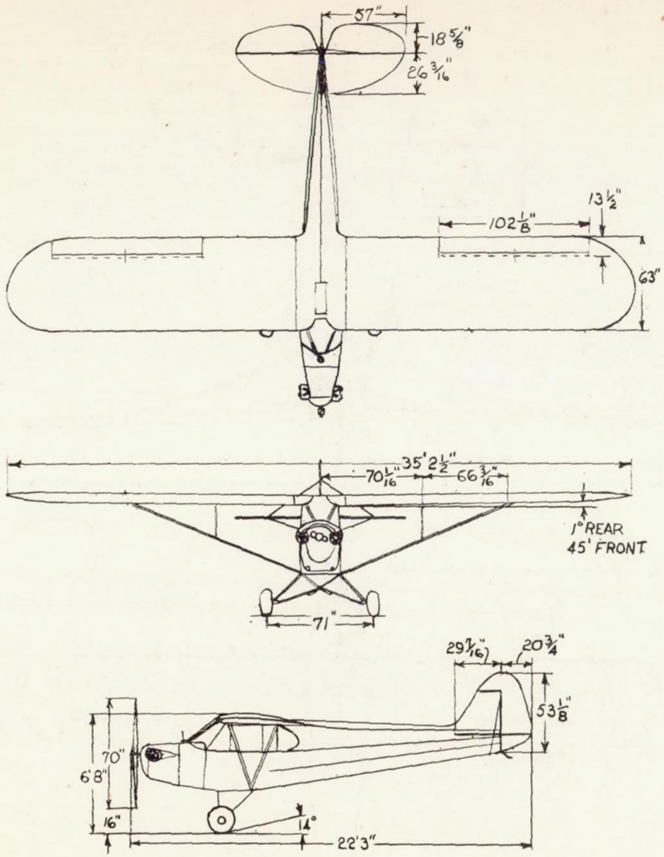
Figure 1.- Concluded.



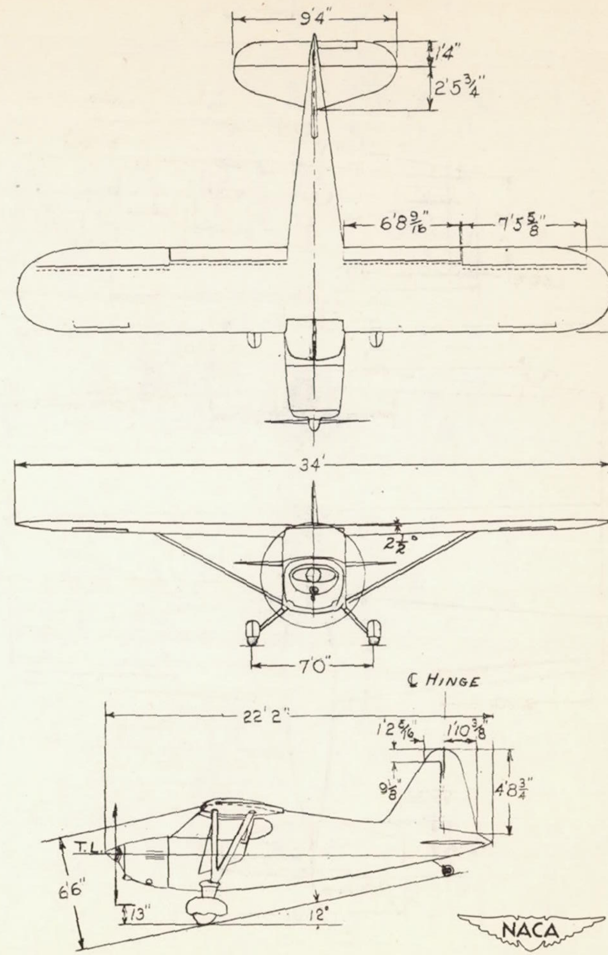
(a) Airplane 1.

(b) Airplane 2.

Figure 2.- Three-view drawings of airplanes.

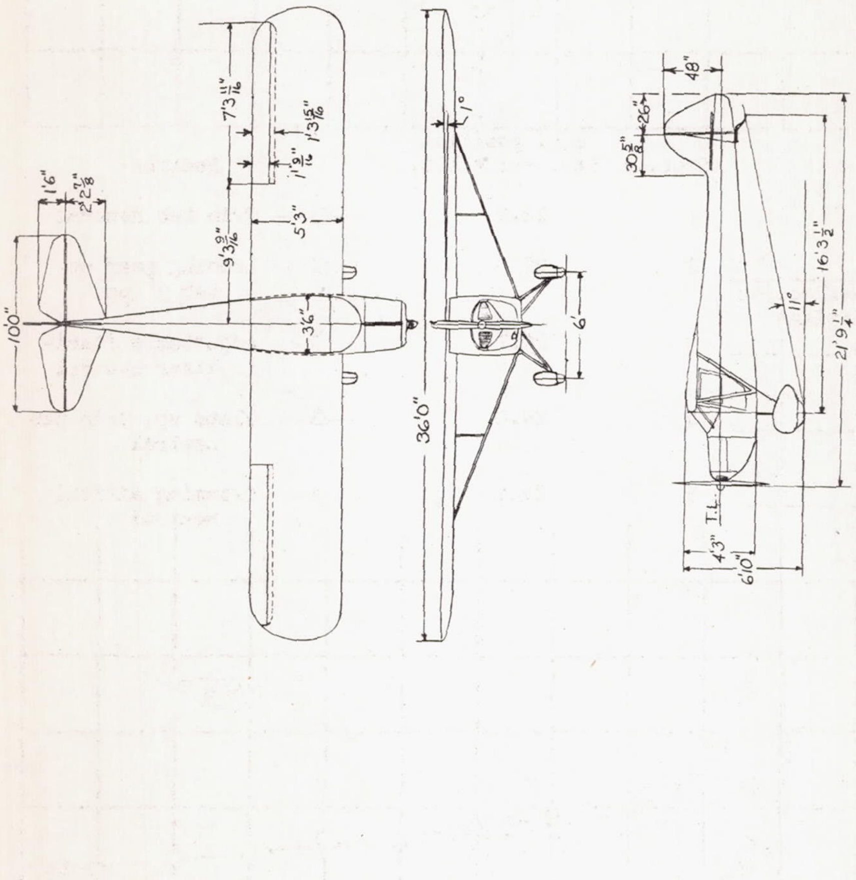


(c) Airplane 3.



(d) Airplane 4.

Figure 2.- Continued.



(e) Airplane 5.

Figure 2.- Concluded.

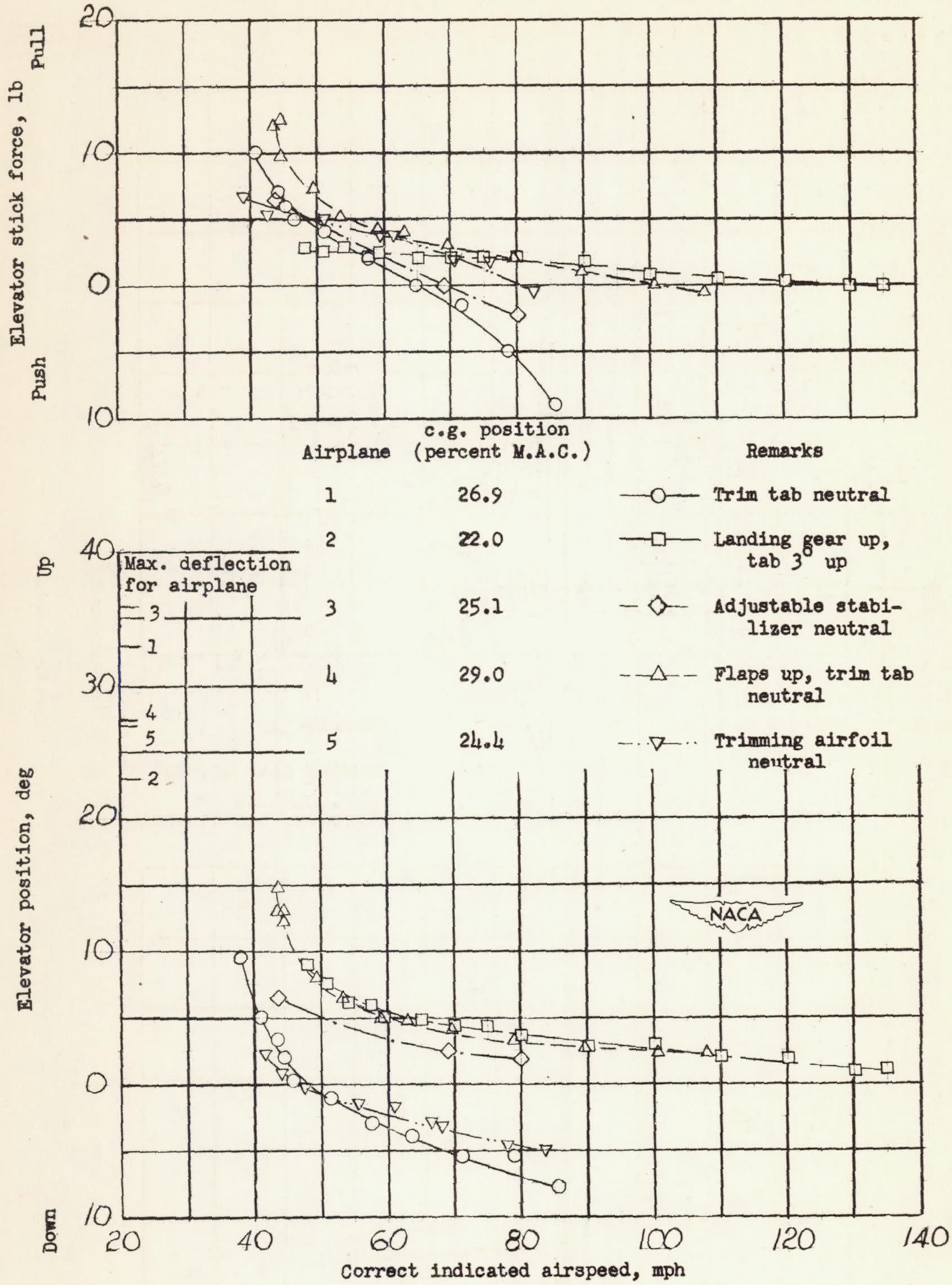


Figure 3.- Static longitudinal stability characteristics. Power-on cruising; airplanes 1, 2, 3, 4, and 5.

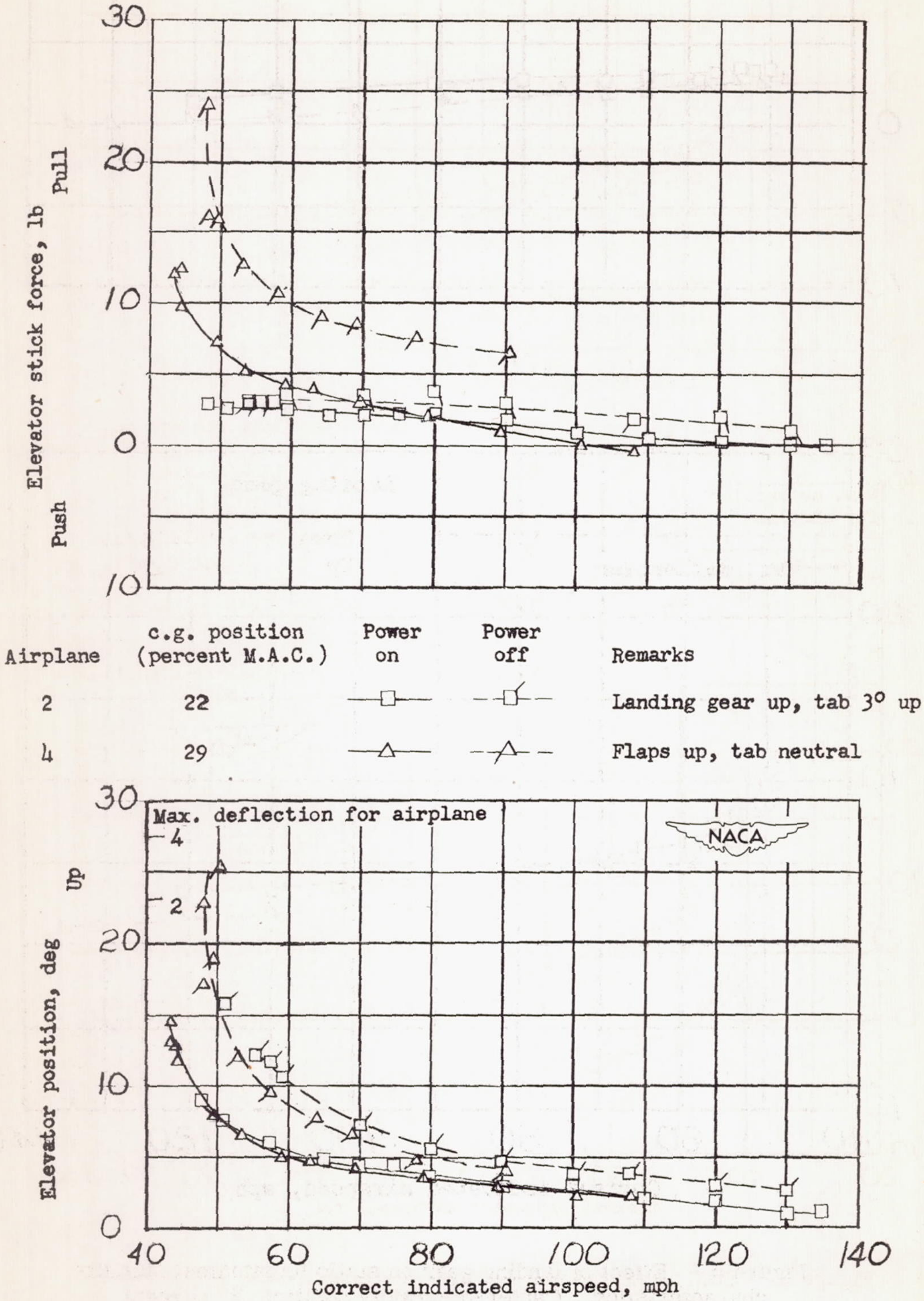


Figure 4.- Effect of engine power on static longitudinal stability characteristics. Airplanes 2 and 4.

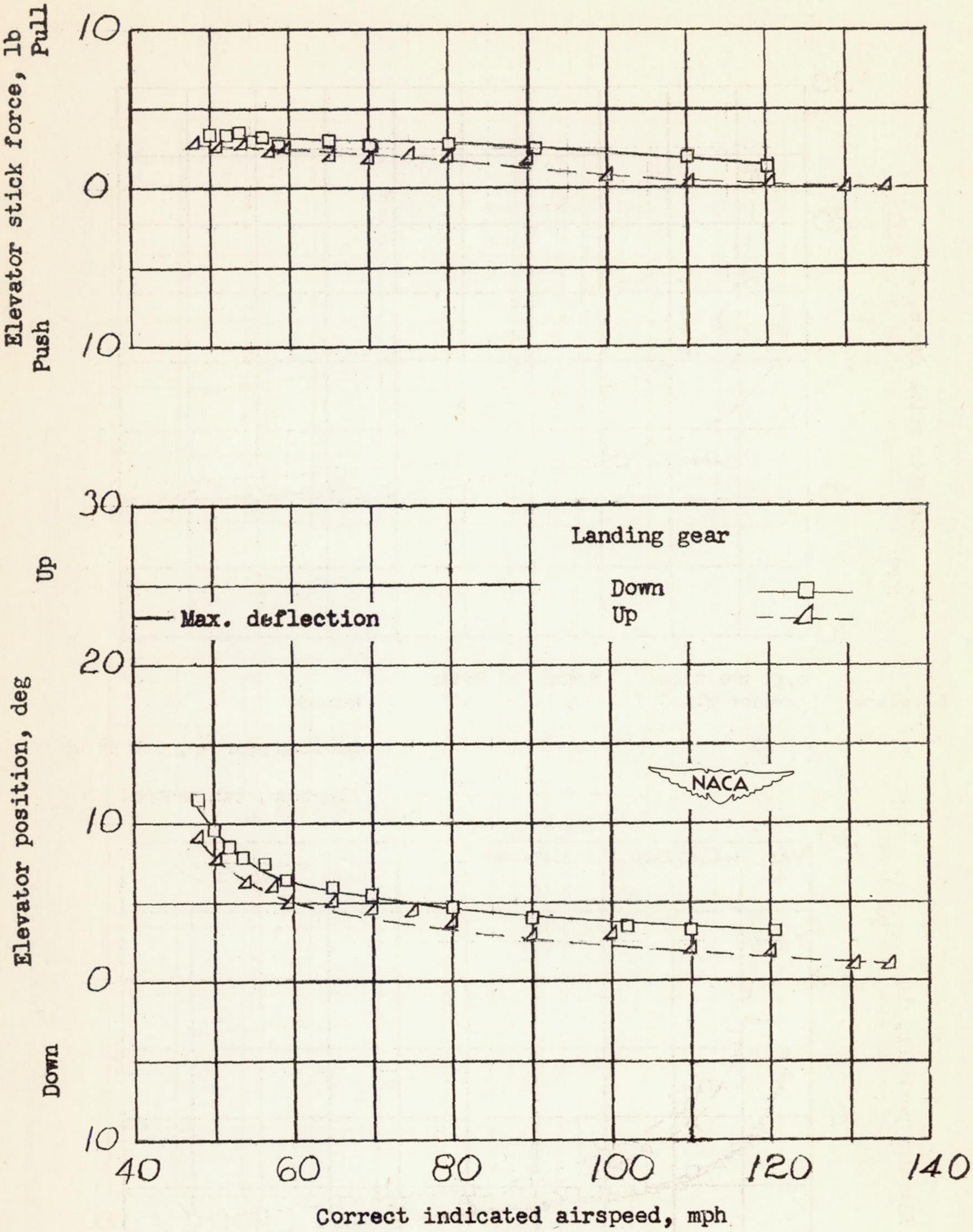


Figure 5.- Effect of landing gear on static longitudinal stability characteristics. Center-of-gravity position, 22 percent M.A.C.; trim tab 3° up; power on; airplane 2.

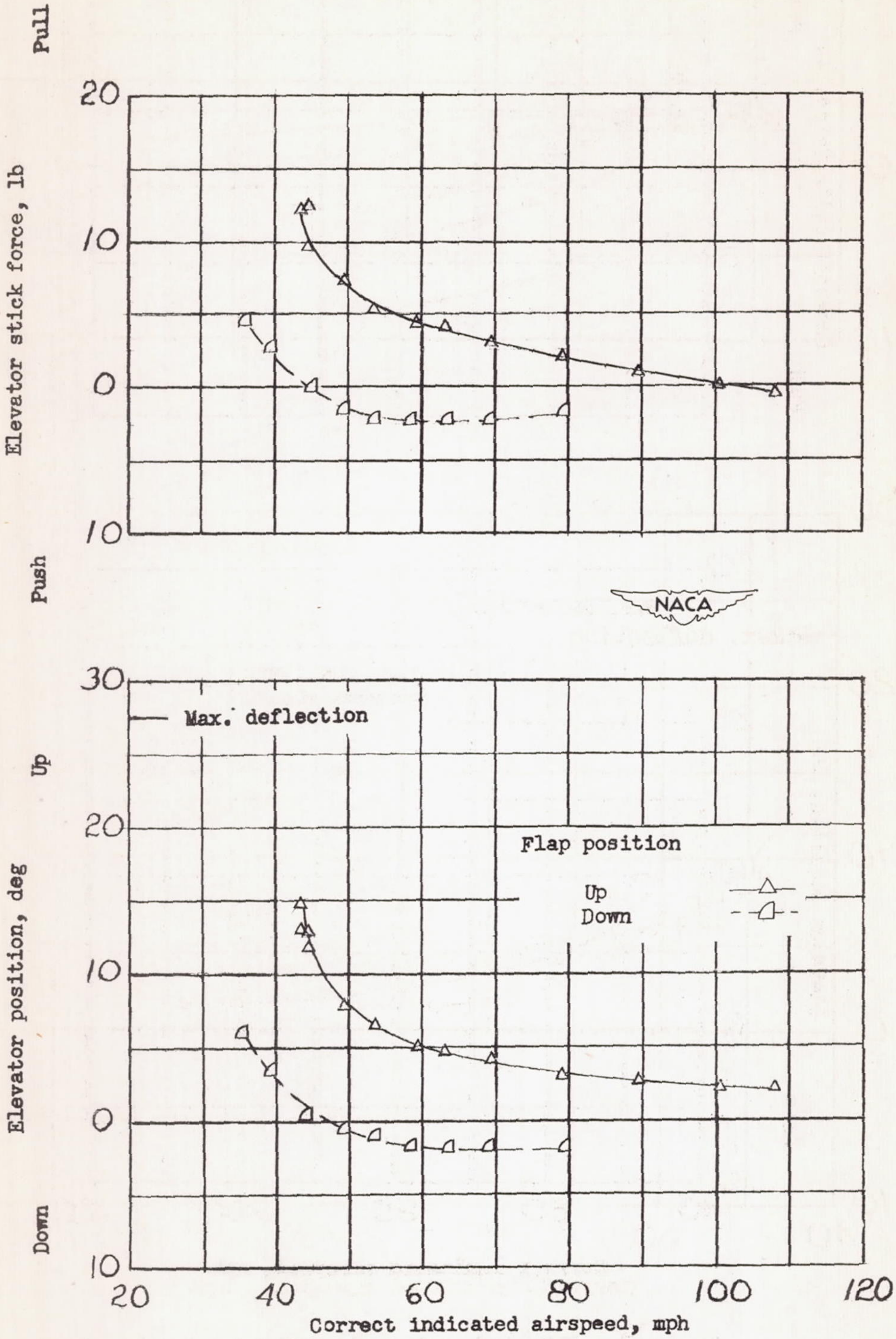


Figure 6.- Effect of flaps on static longitudinal stability characteristics with power on. Center-of-gravity position, 29 percent M.A.C.; trim tab neutral; airplane 4.

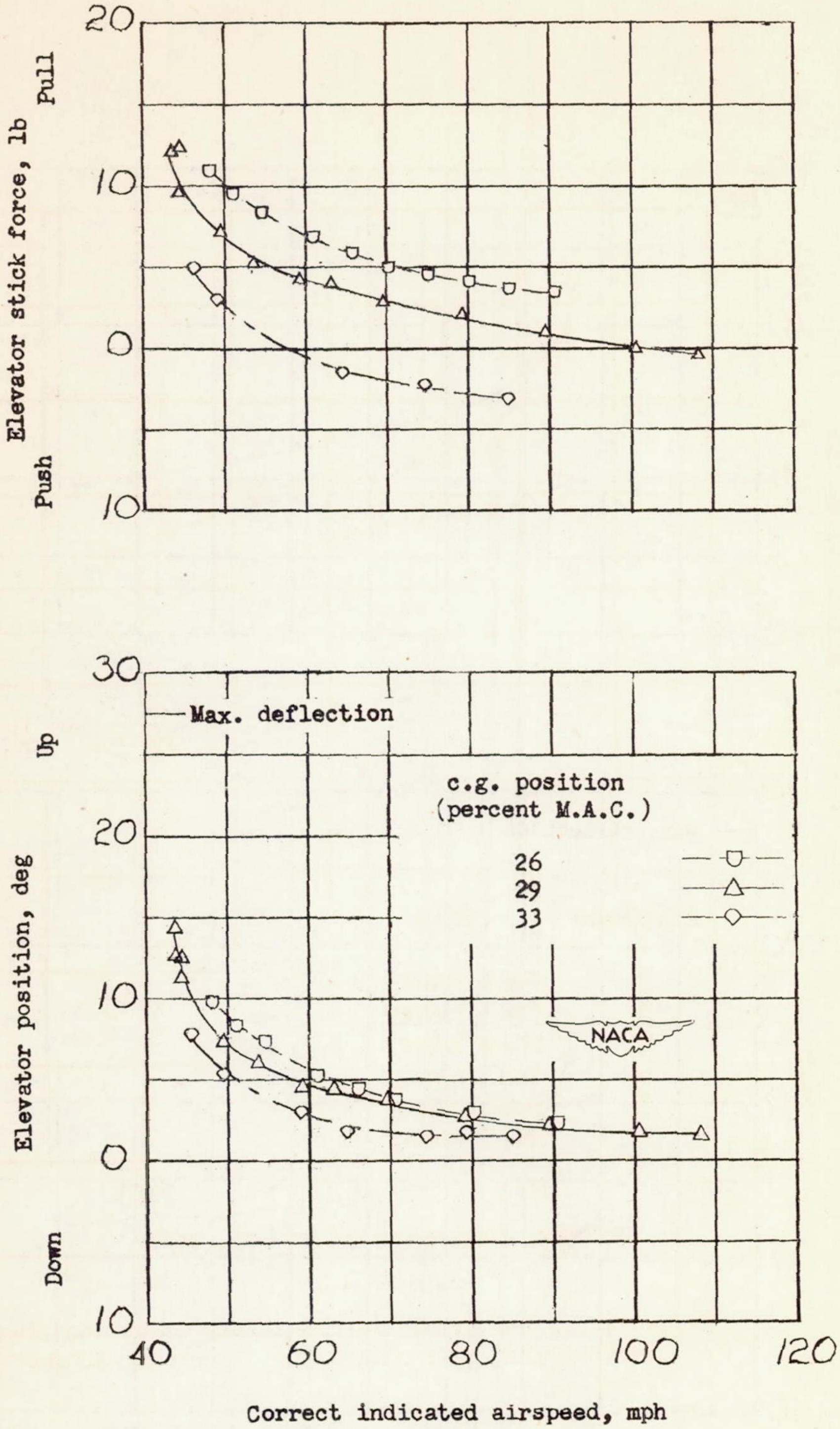


Figure 7.- Effect of center-of-gravity position on static longitudinal stability. Trim tab neutral; power on; flaps up; airplane 4.

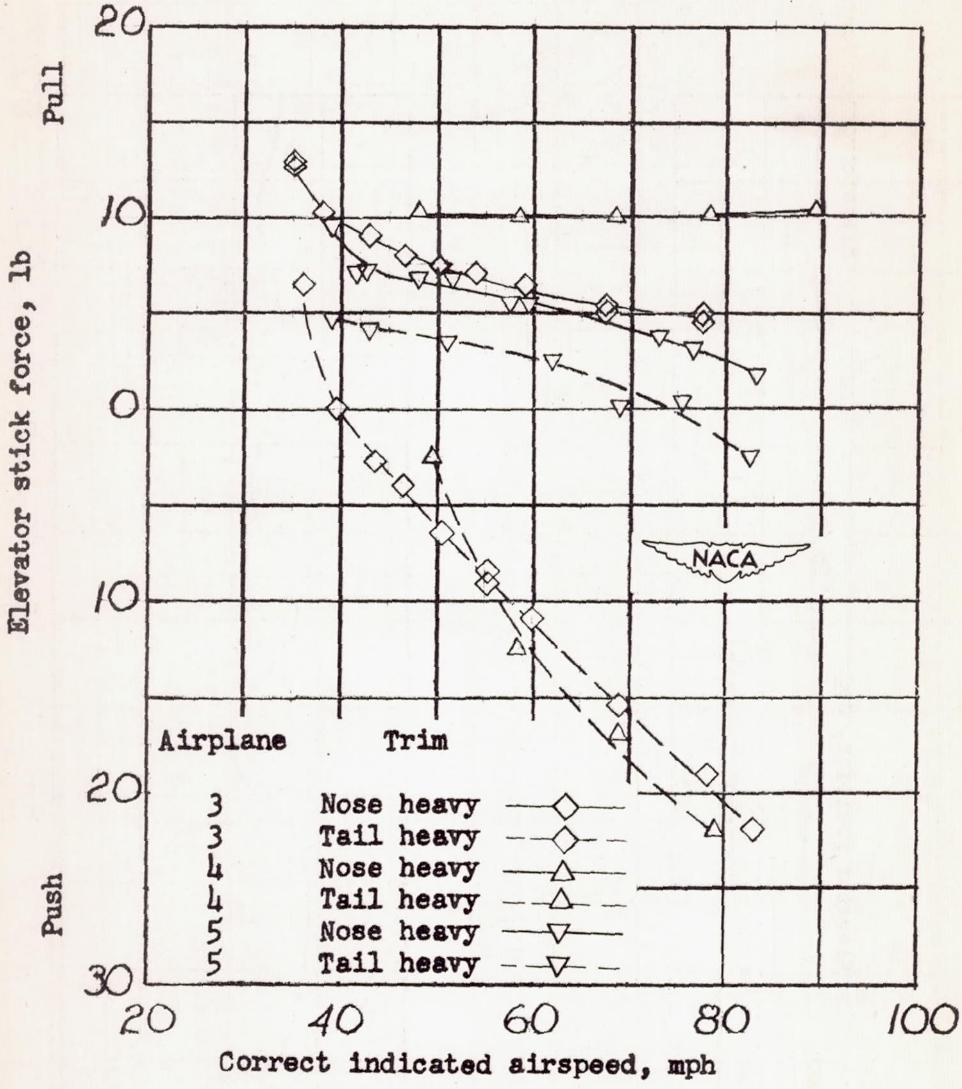


Figure 8.- Effect of trim-device setting on the variation of elevator stick force with speed. Power on; airplanes 3, 4, and 5.

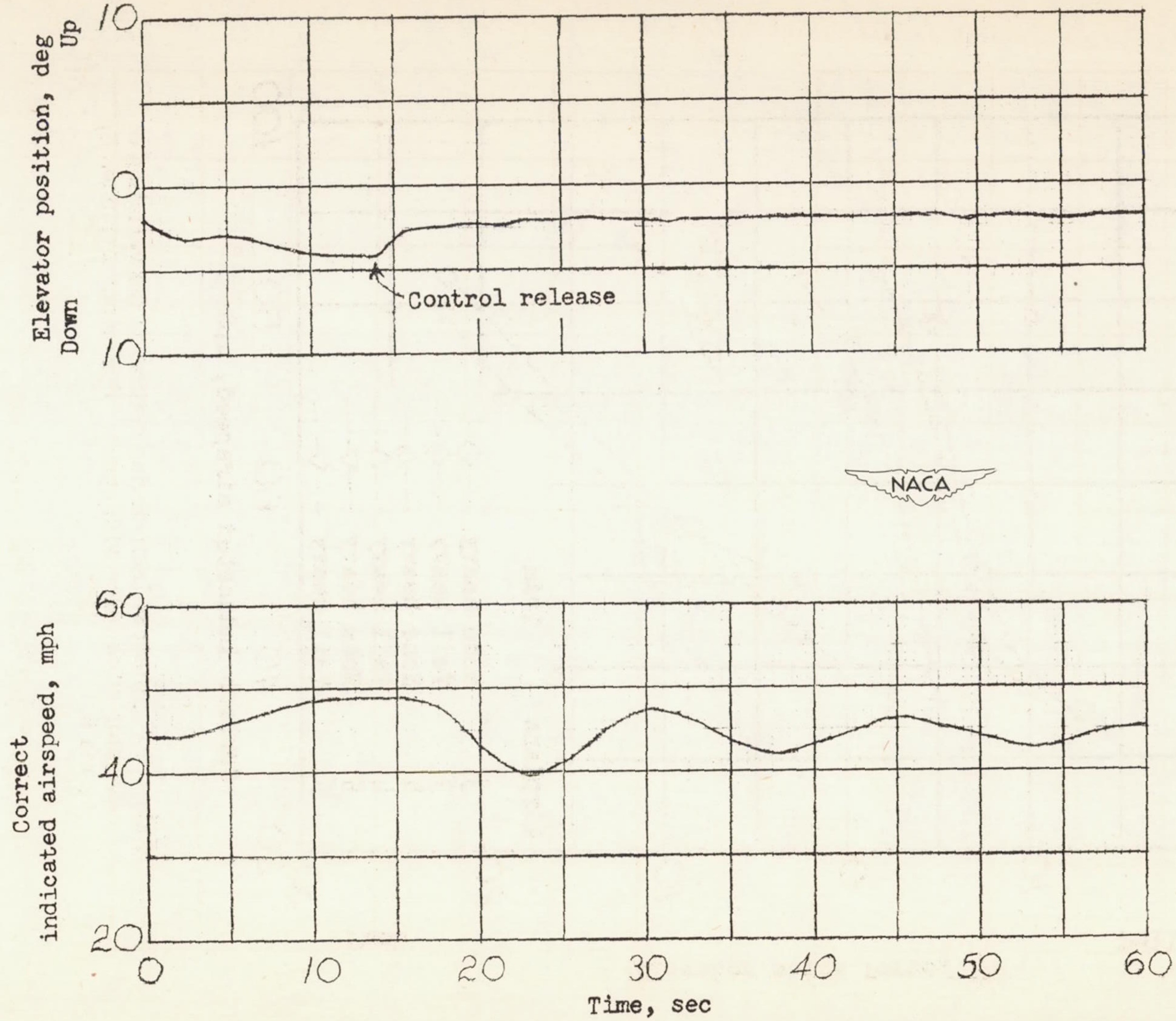


Figure 9.- Time history of a typical longitudinal oscillation. Flaps up; power on; rearward center-of-gravity position; airplane 4.

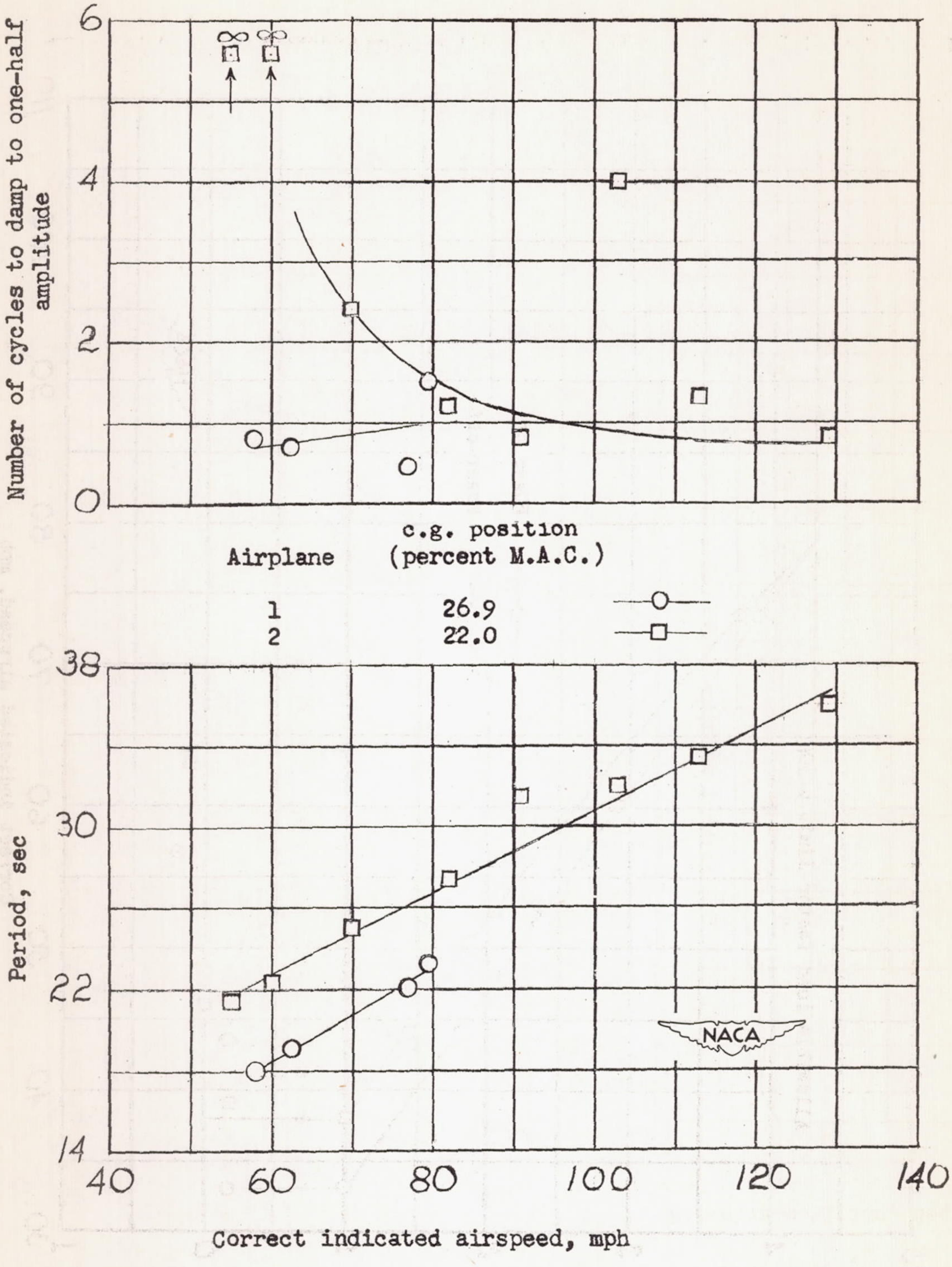


Figure 10.- Period and damping characteristics of longitudinal oscillations. Power on; airplanes 1 and 2.

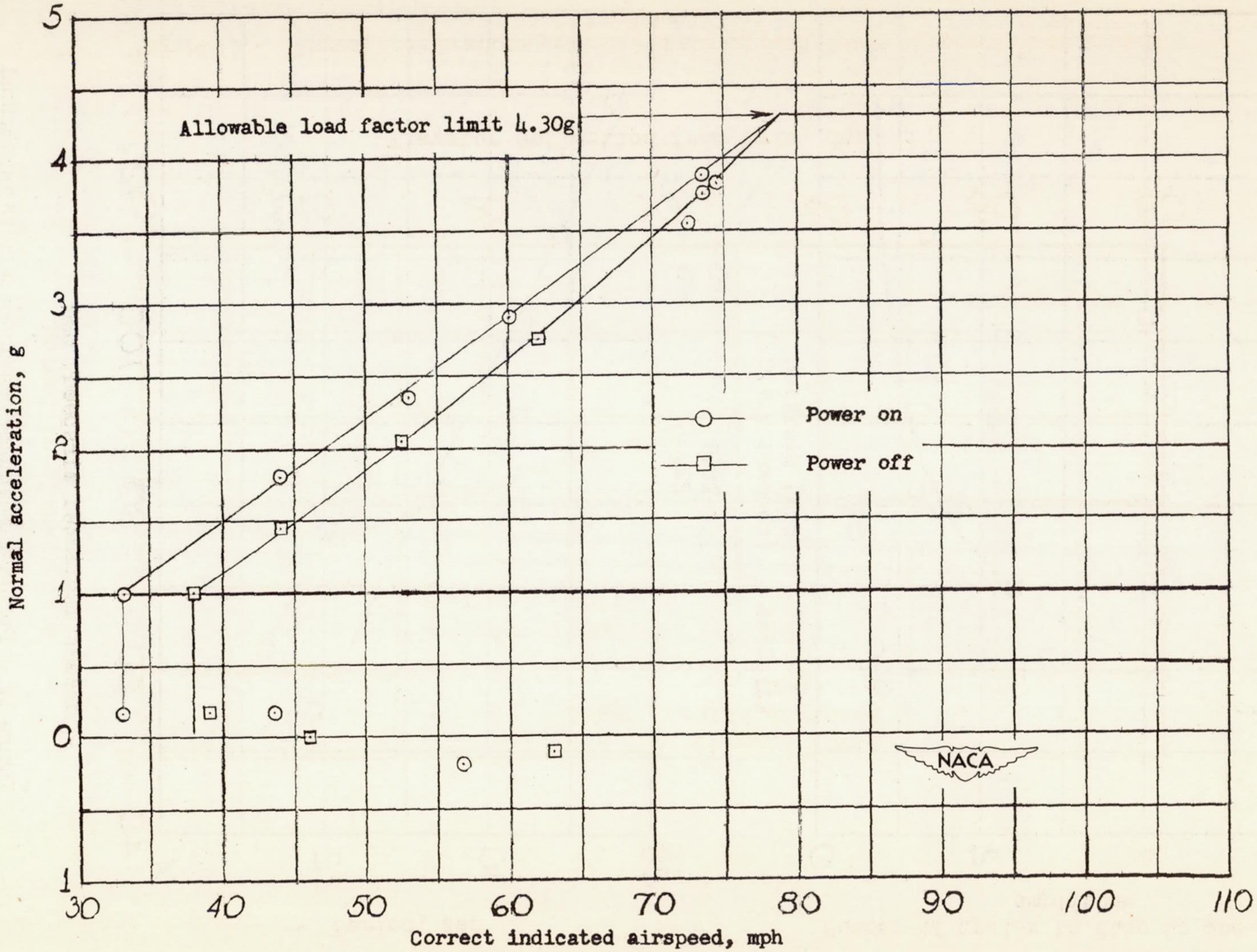


Figure 11.- Normal accelerations produced by abrupt pull-ups and push-downs from level flight with power on and off using full elevator control. Airplane 3.

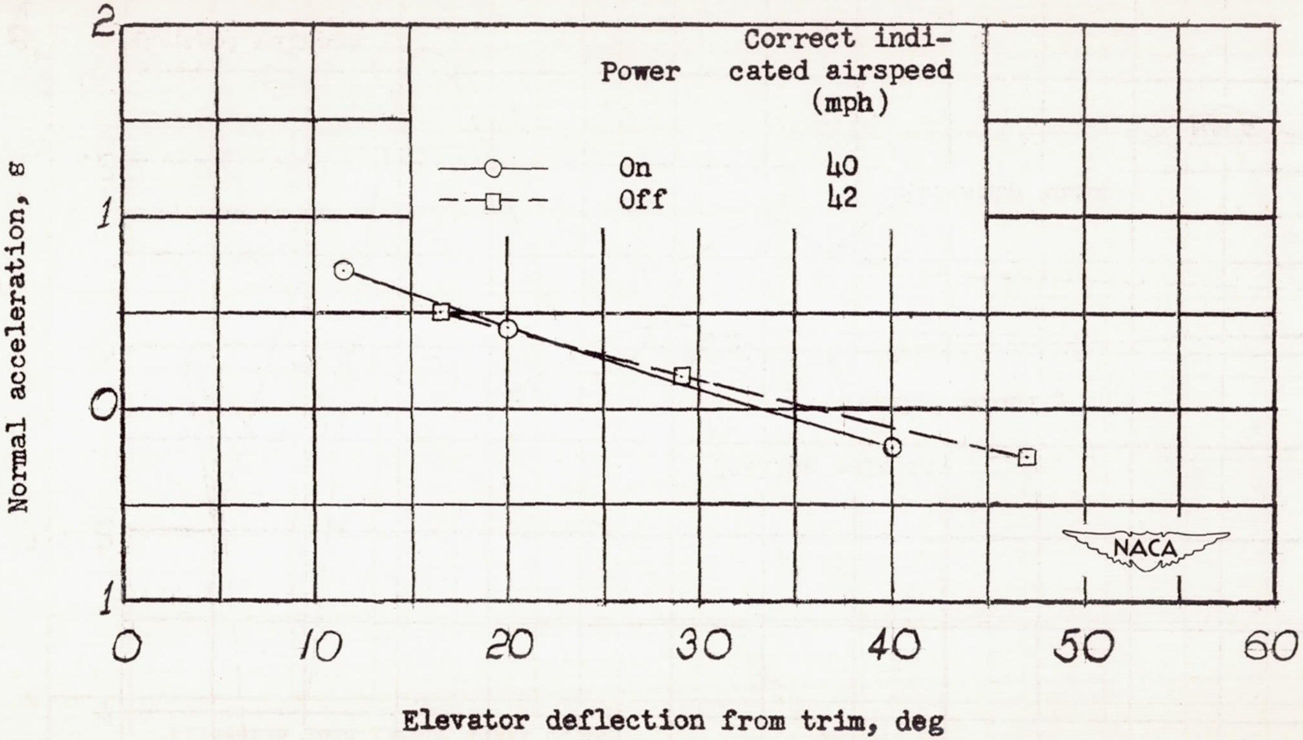


Figure 12.- Normal accelerations produced in abrupt push-downs at speeds close to stall. Airplane 1.

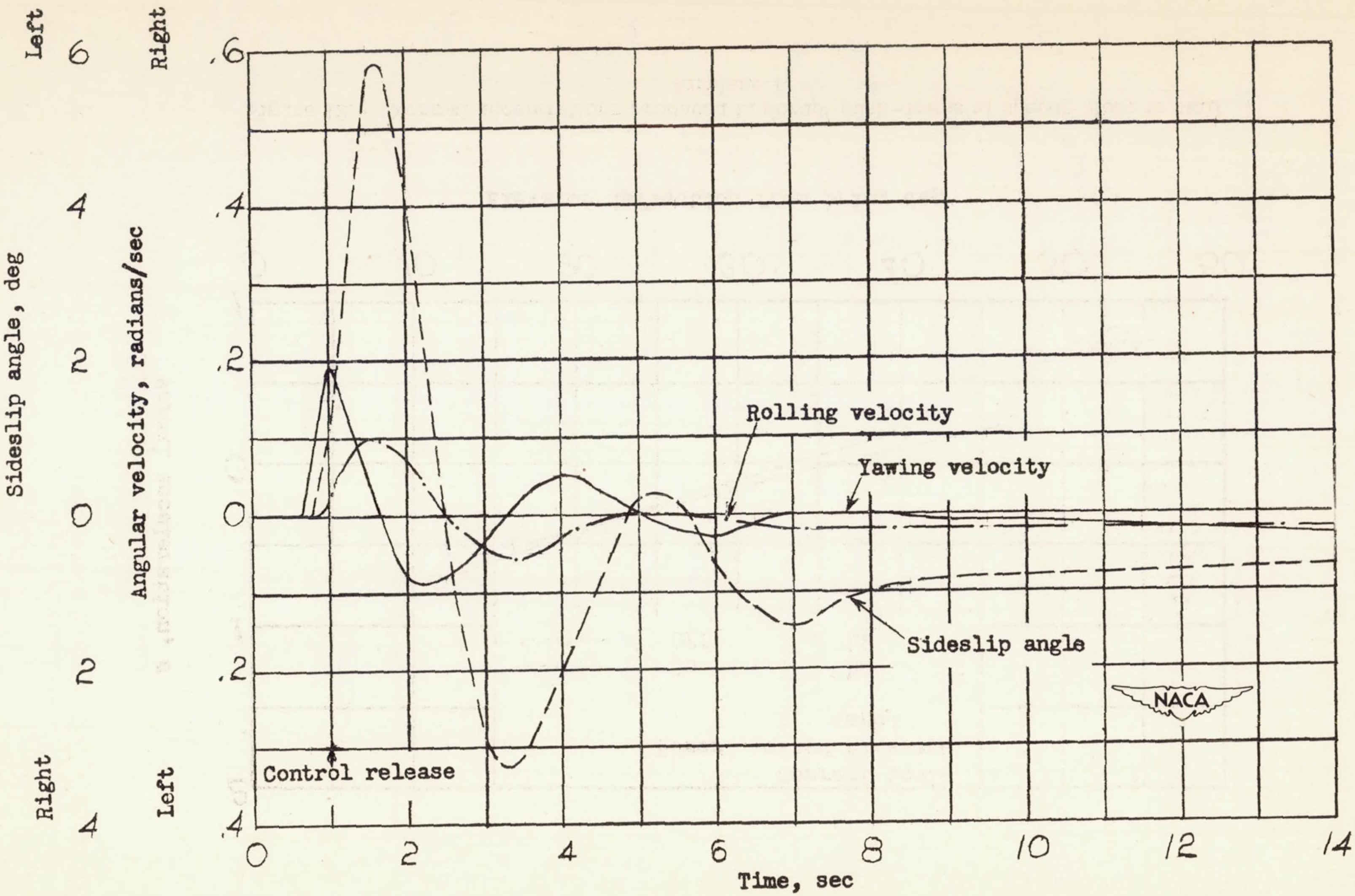


Figure 13.- Relation between yawing velocity, rolling velocity, and sideslip angle in a typical lateral oscillation with power on and flaps up. Airplane 4.

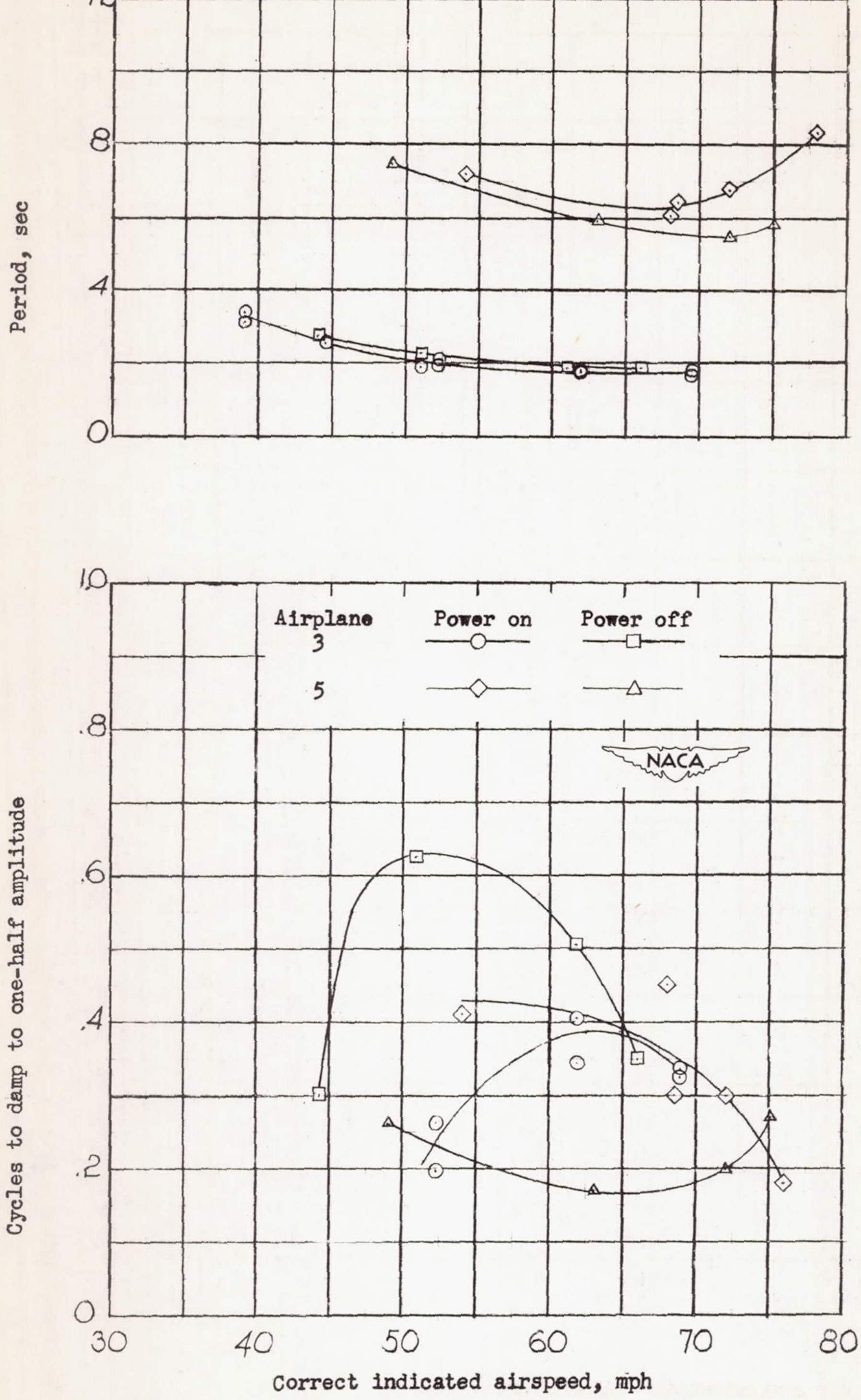


Figure 14.- Period and damping characteristics for lateral oscillations. Airplanes 3 and 5.

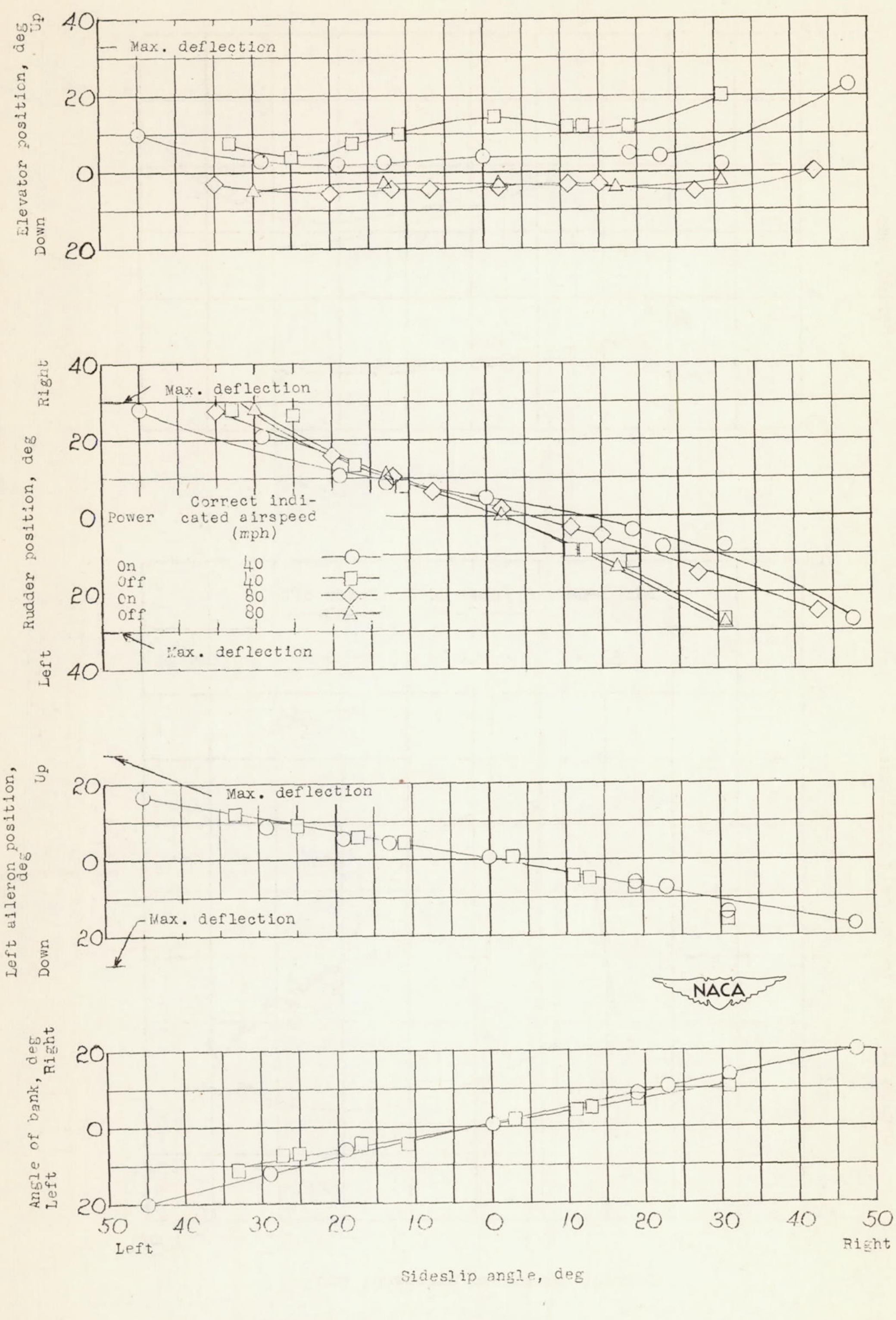


Figure 15.- Sideslip characteristics. Airplane 1.

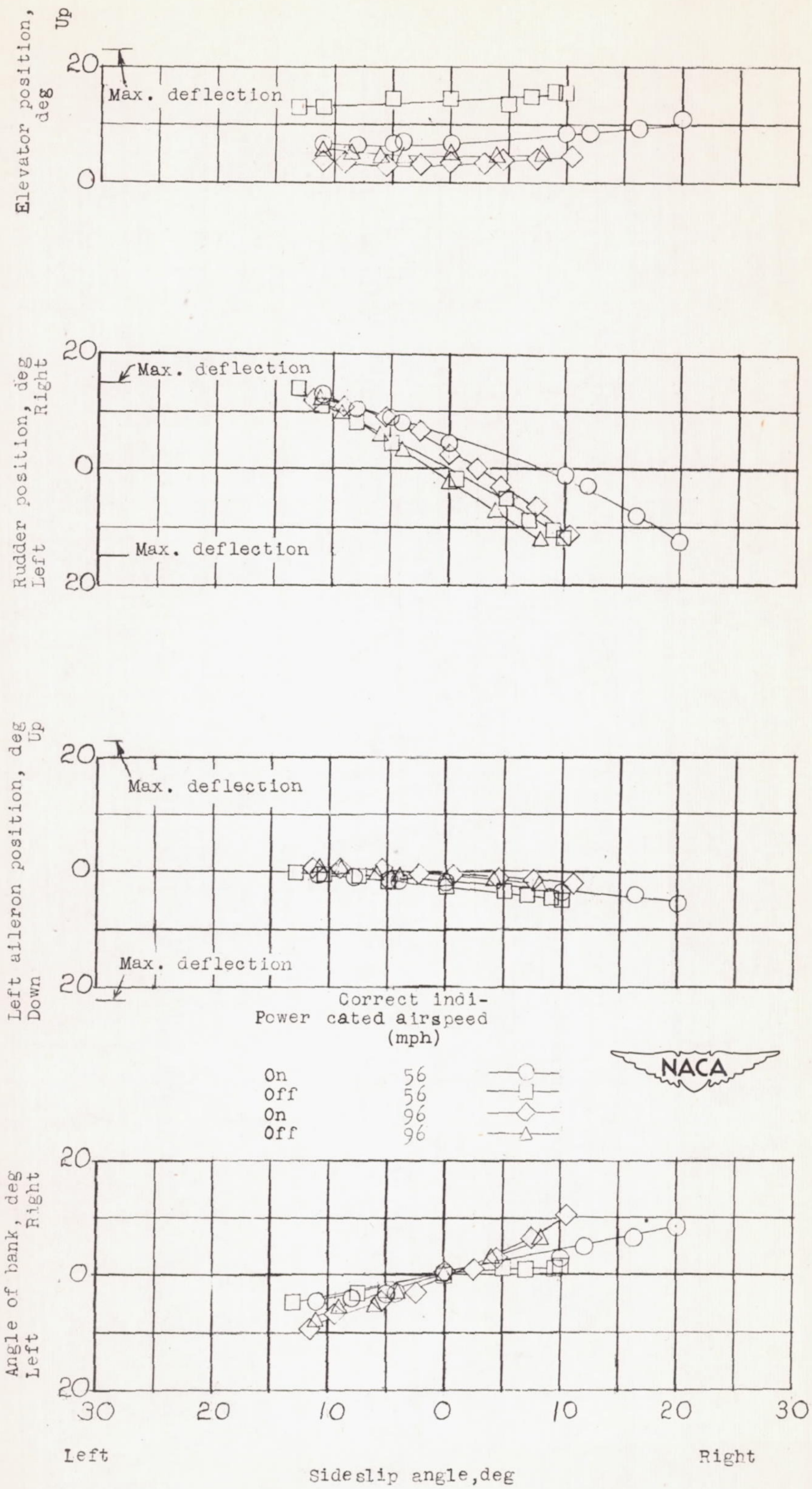


Figure 16.- Sideslip characteristics. Landing gear down; airplane 2.

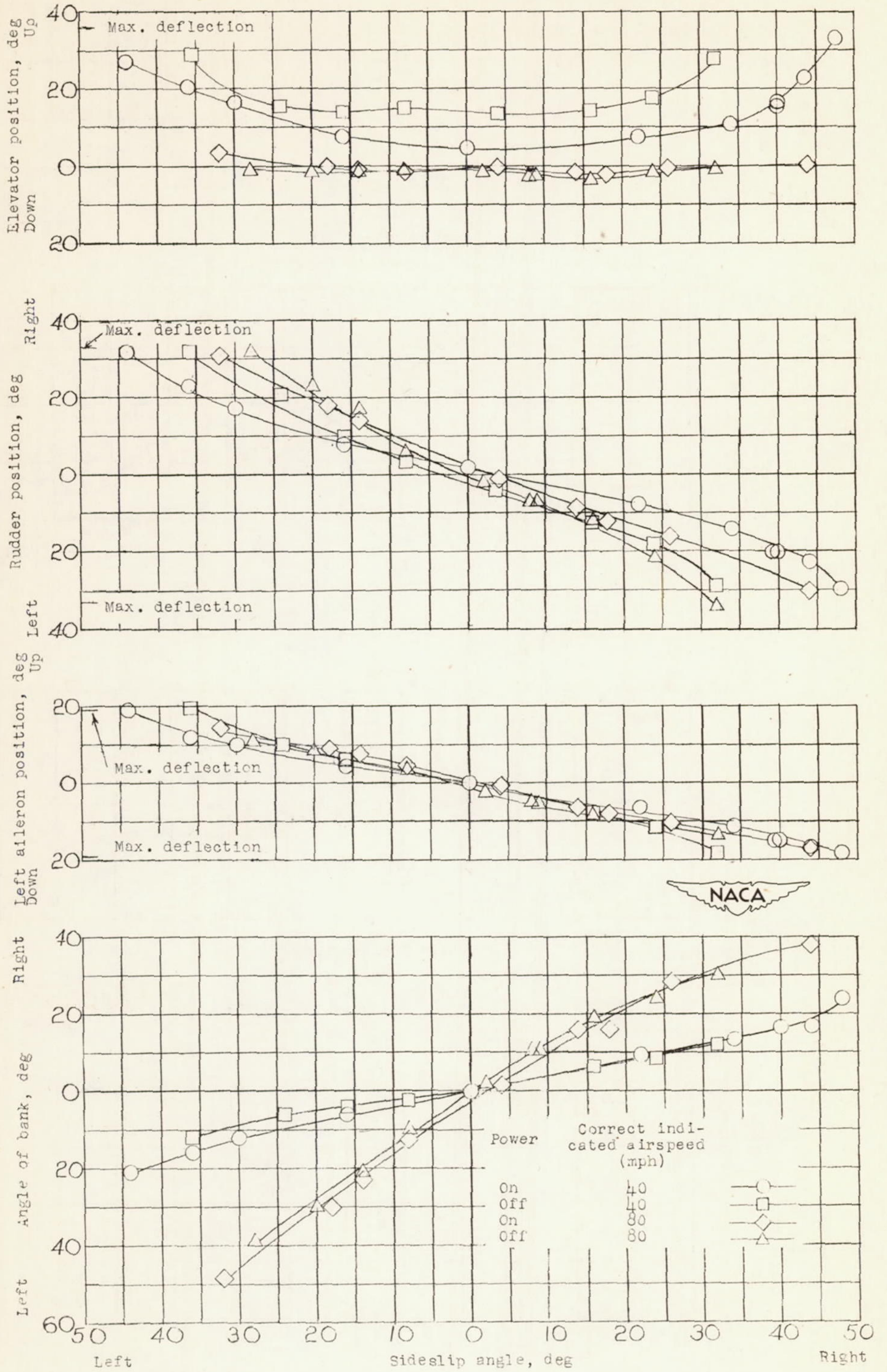
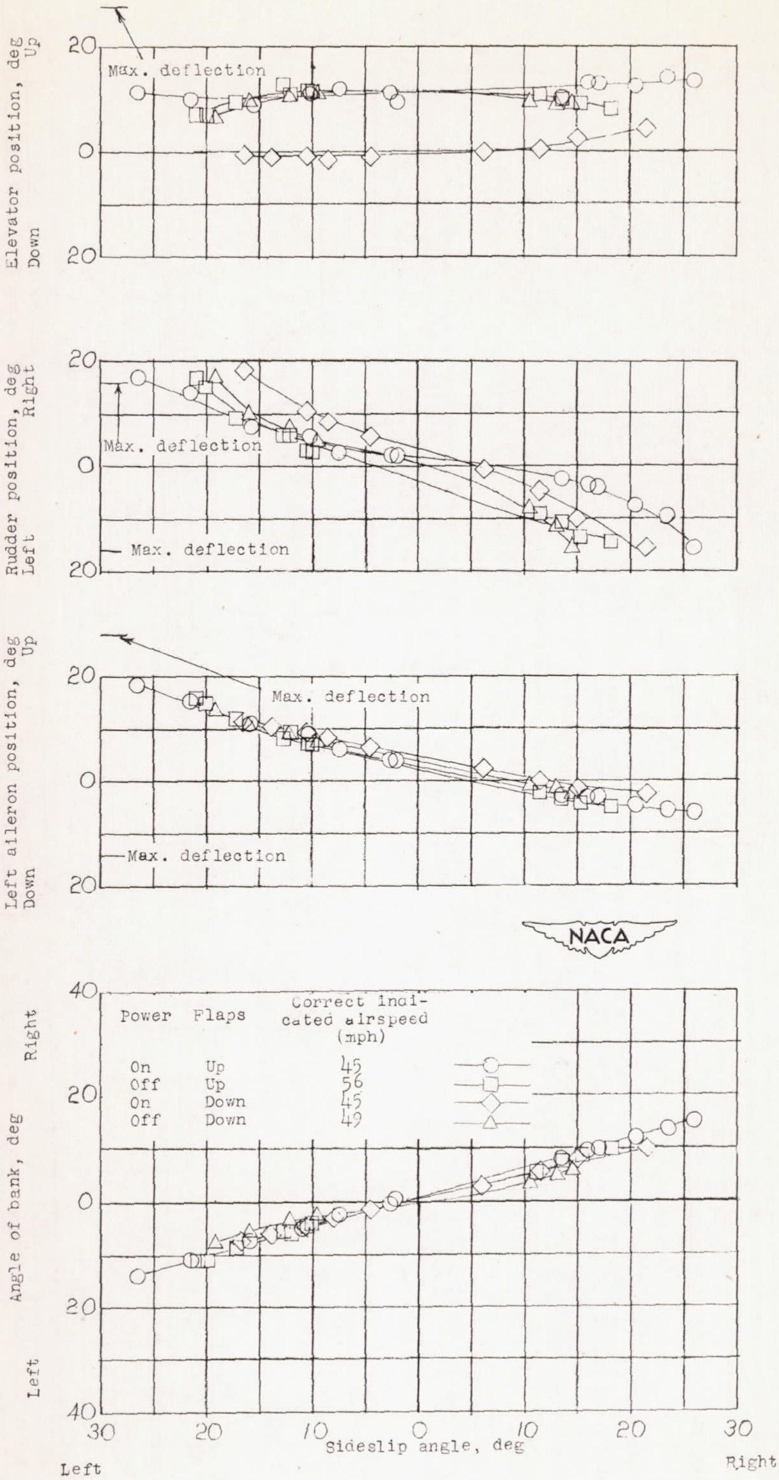
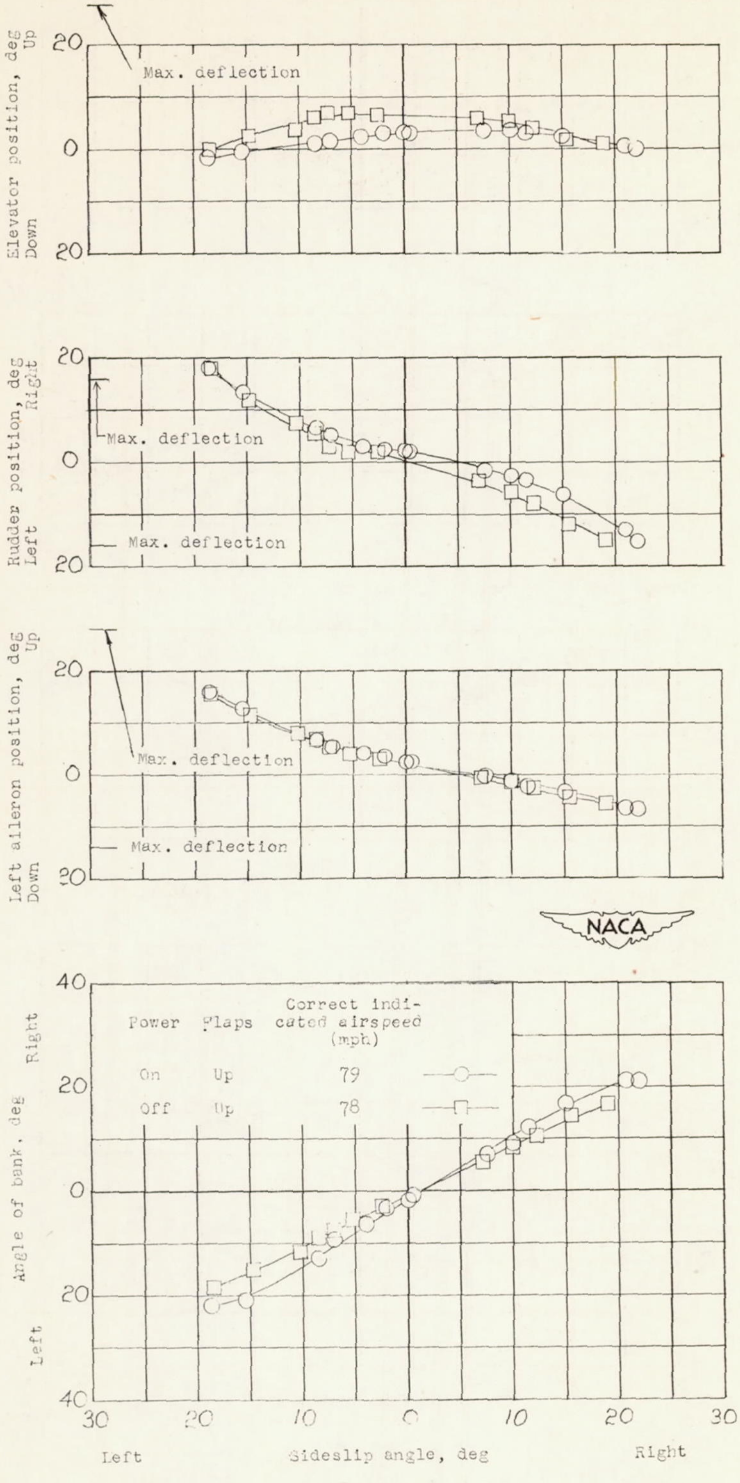


Figure 17.- Sideslip characteristics. Airplane 3.



(a) Low speed.

Figure 18.- Sideslip characteristics. Airplane 4.



(b) High speed.

Figure 18.- Concluded.

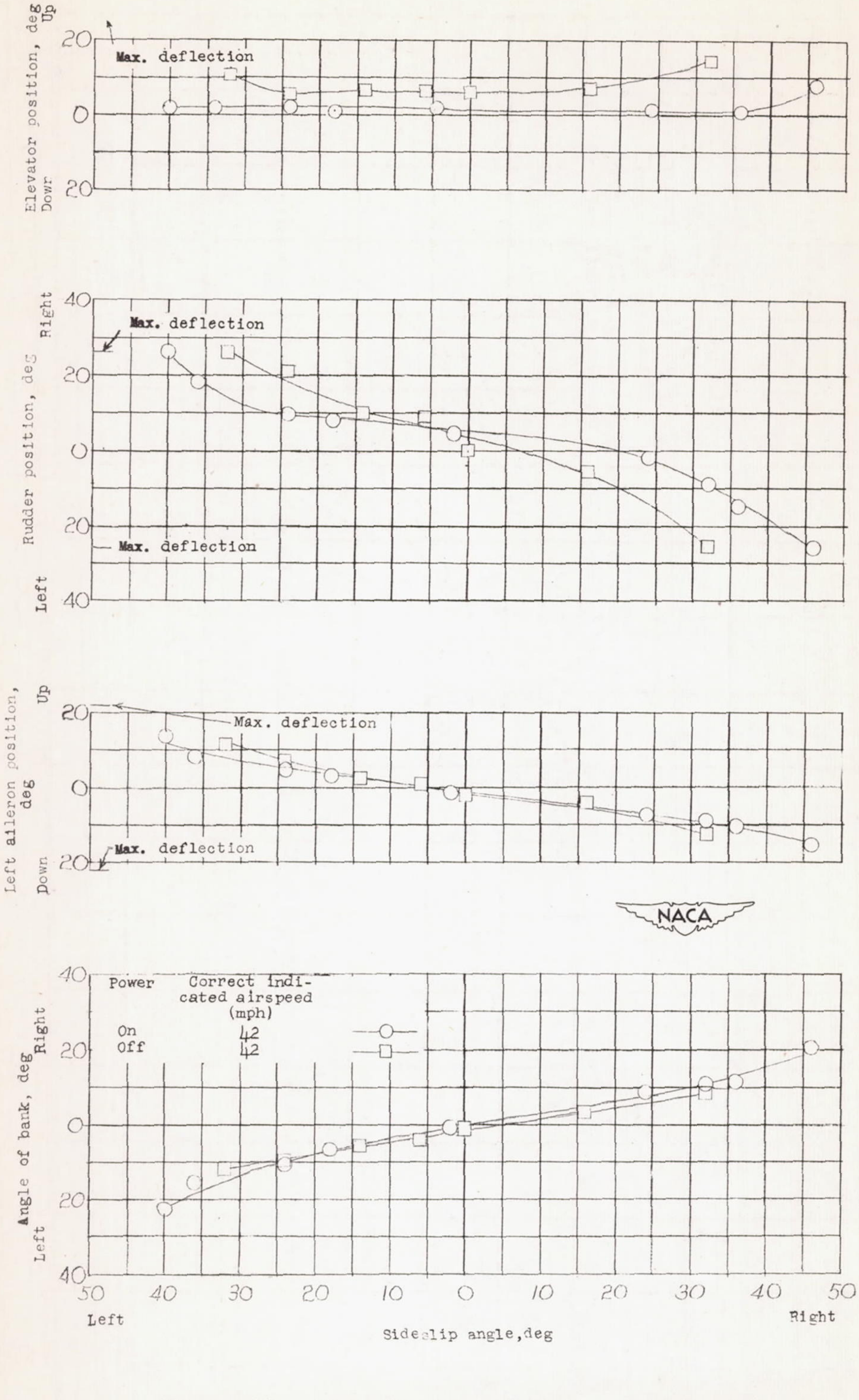


Figure 19.- Sideslip characteristics. Airplane 5.

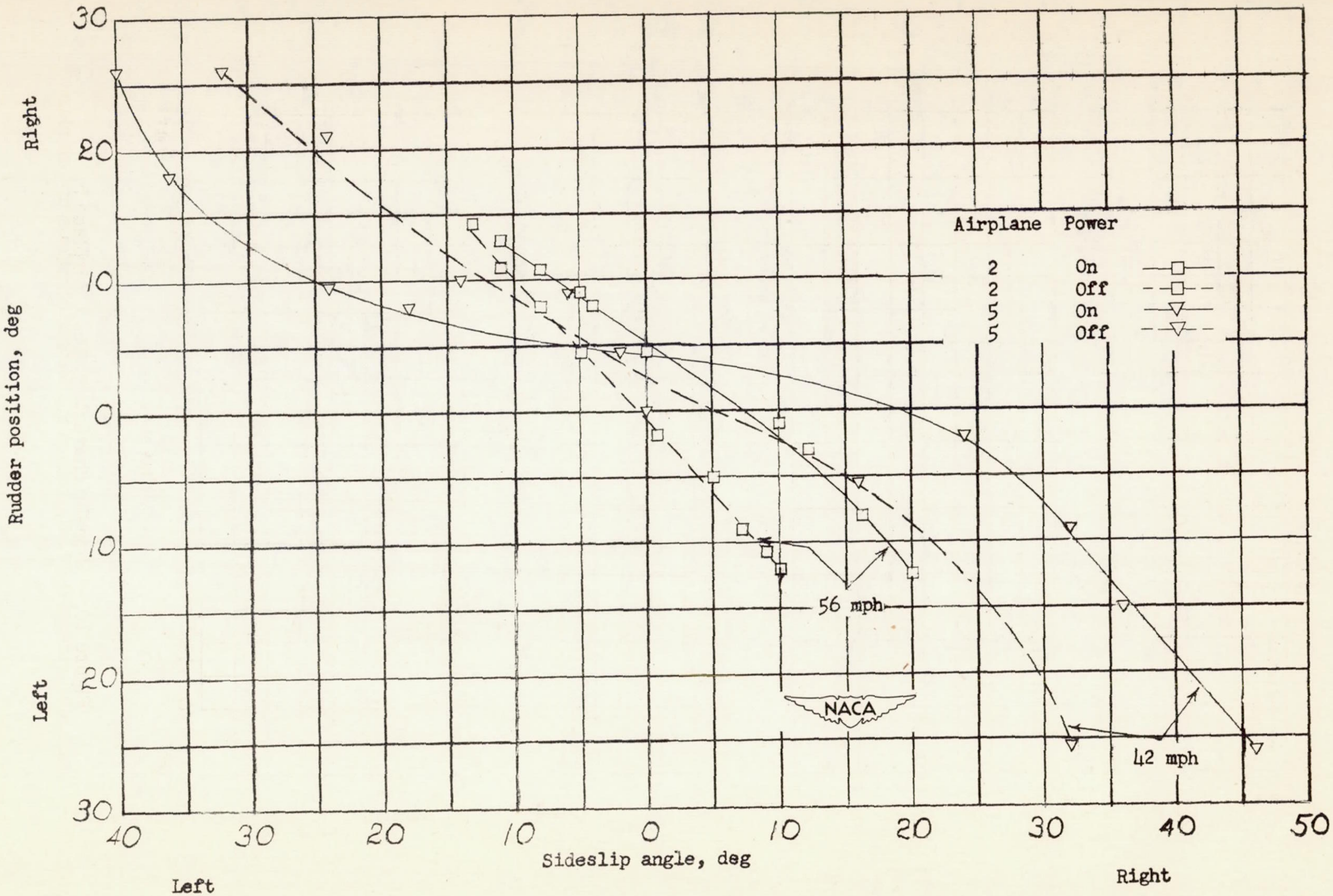


Figure 20.- Relative directional stability of two of the airplanes tested. Airplanes 2 and 5.

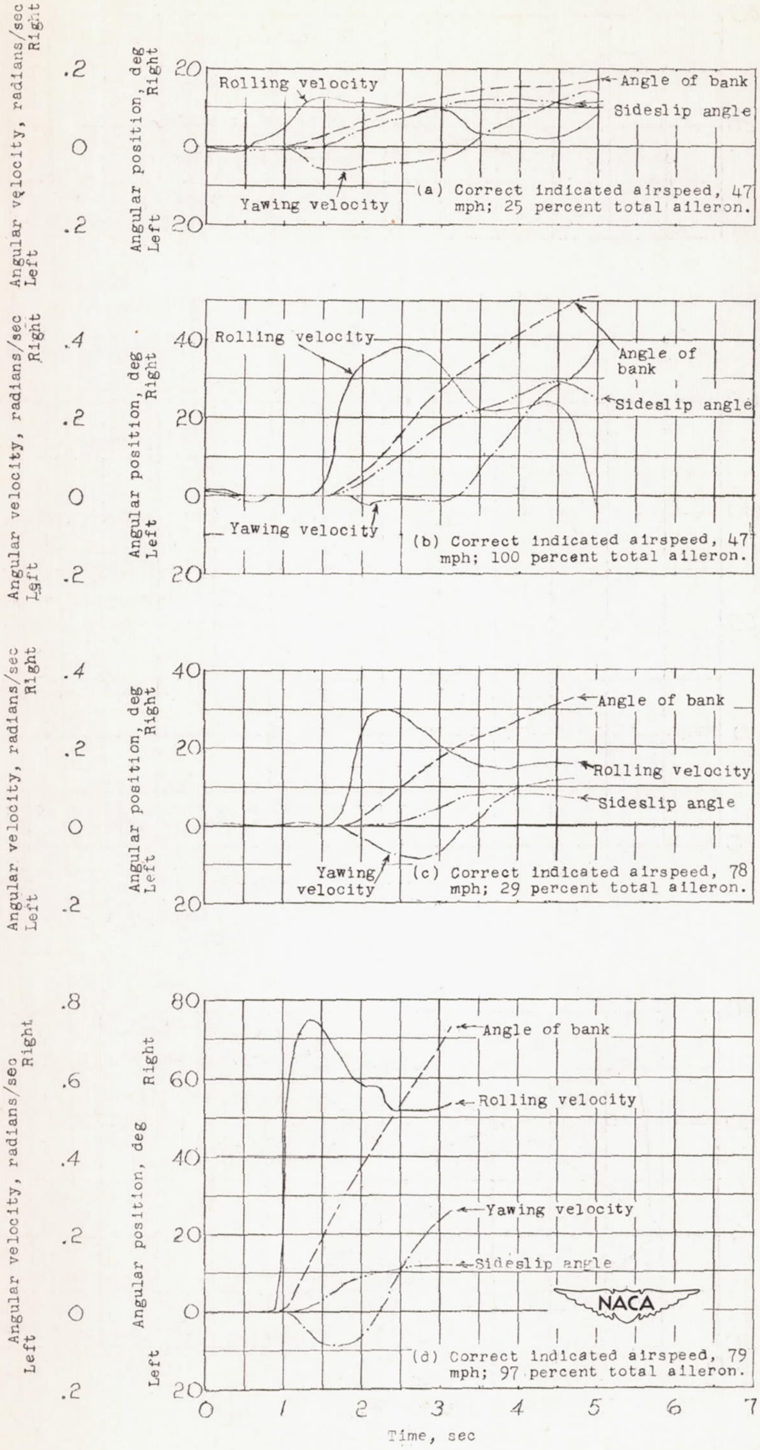


Figure 21.- Time histories of four aileron rolls. Power off; flaps up; airplane 4.

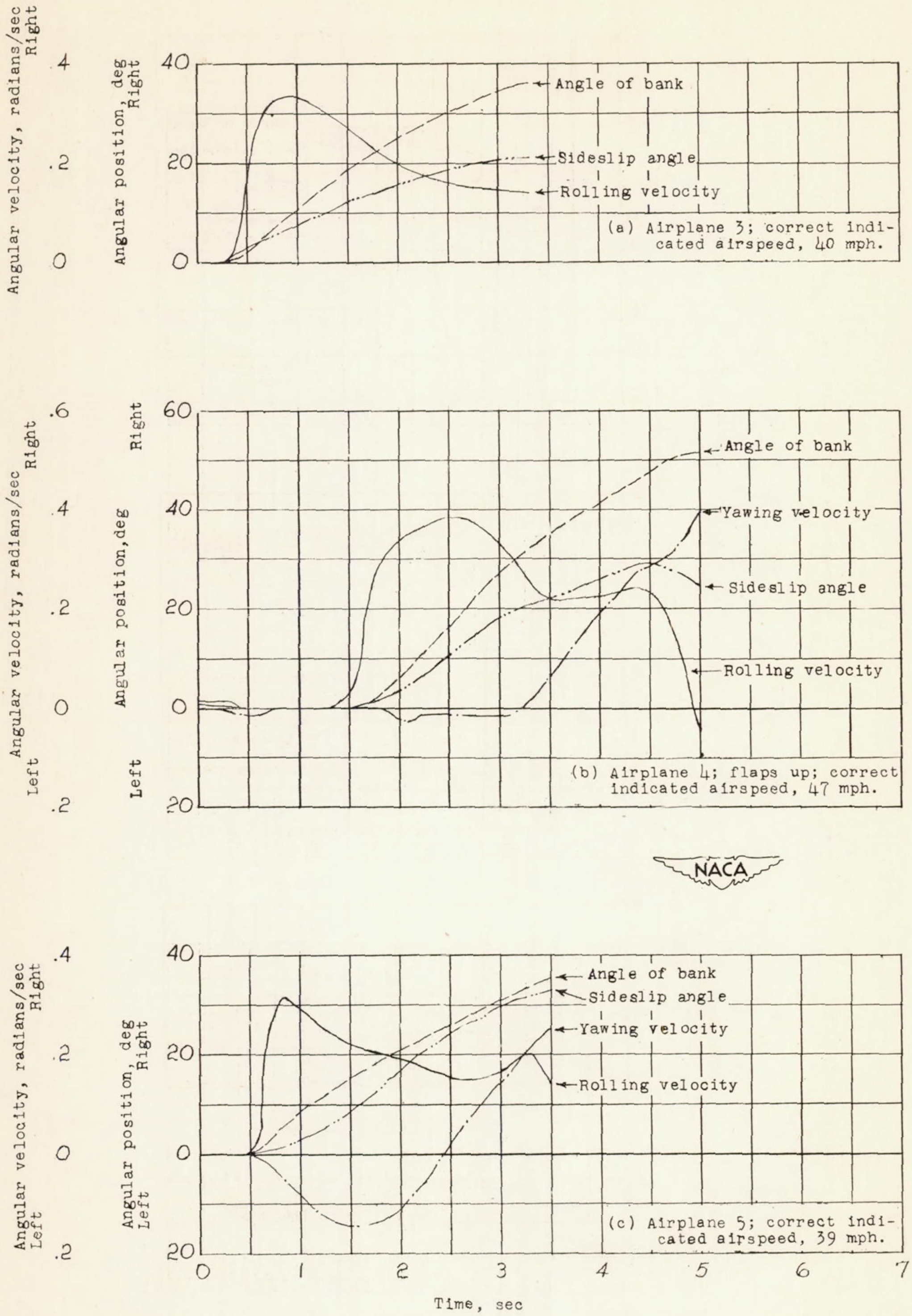


Figure 22.- Time histories of aileron rolls at low speed and full aileron for three airplanes with power off.

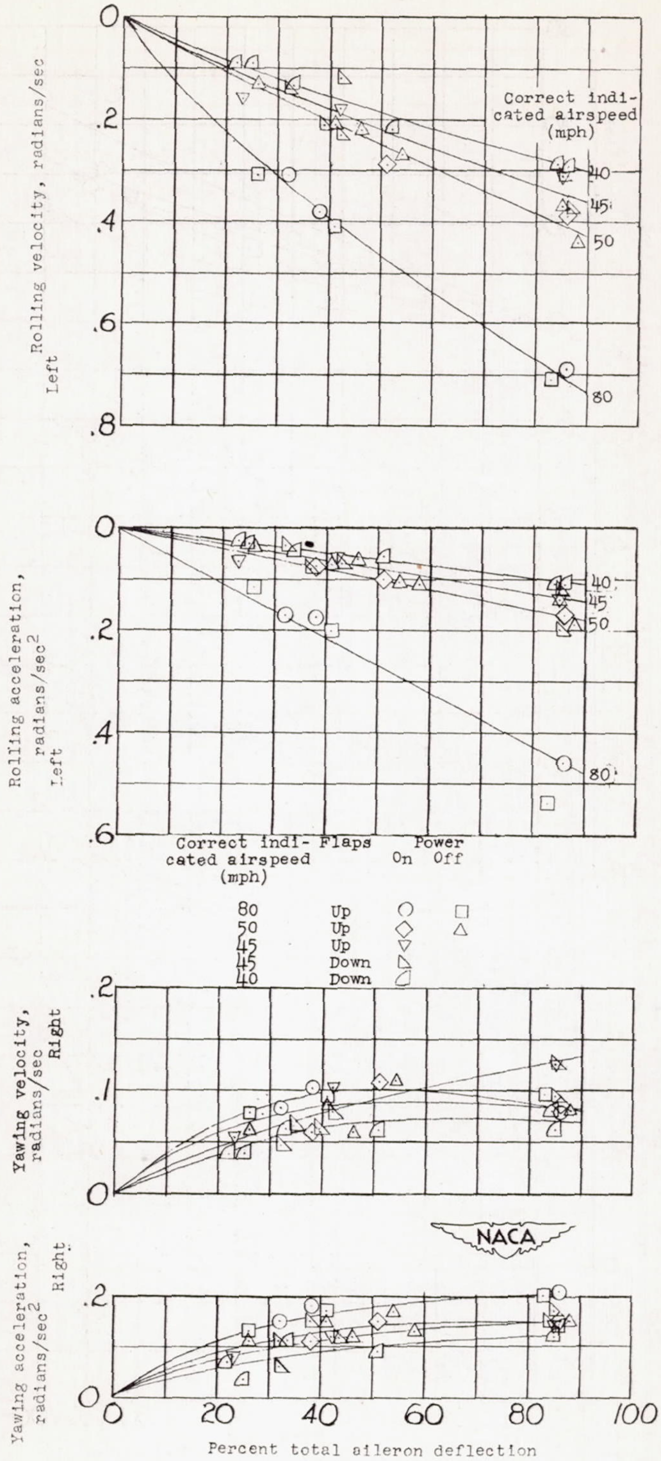


Figure 23.- Aileron characteristics. Airplane 4.

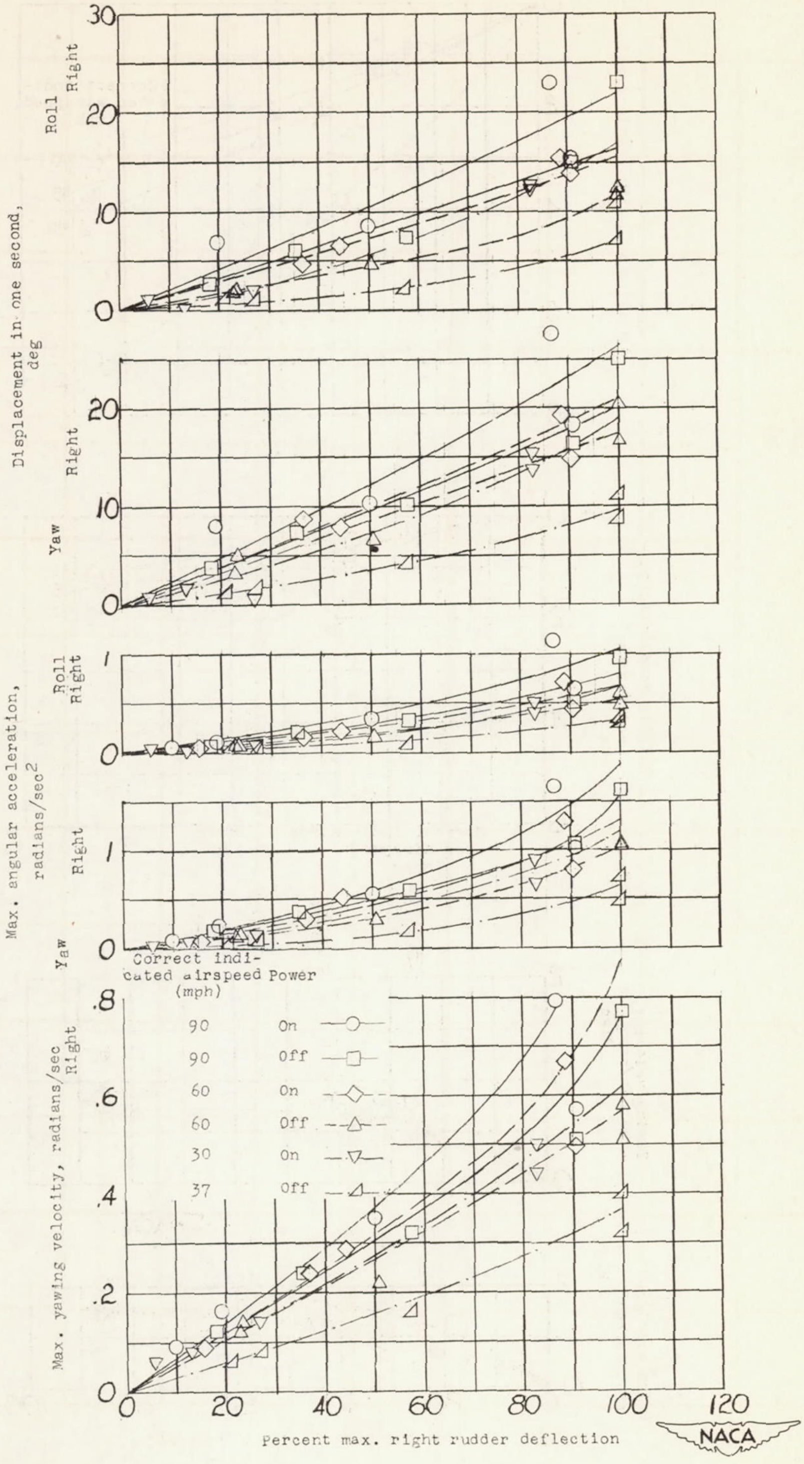


Figure 24.- The maximum yawing velocities, yawing and rolling accelerations, and displacements in yaw and roll produced by abrupt rudder deflections at various speeds. Airplane 1.

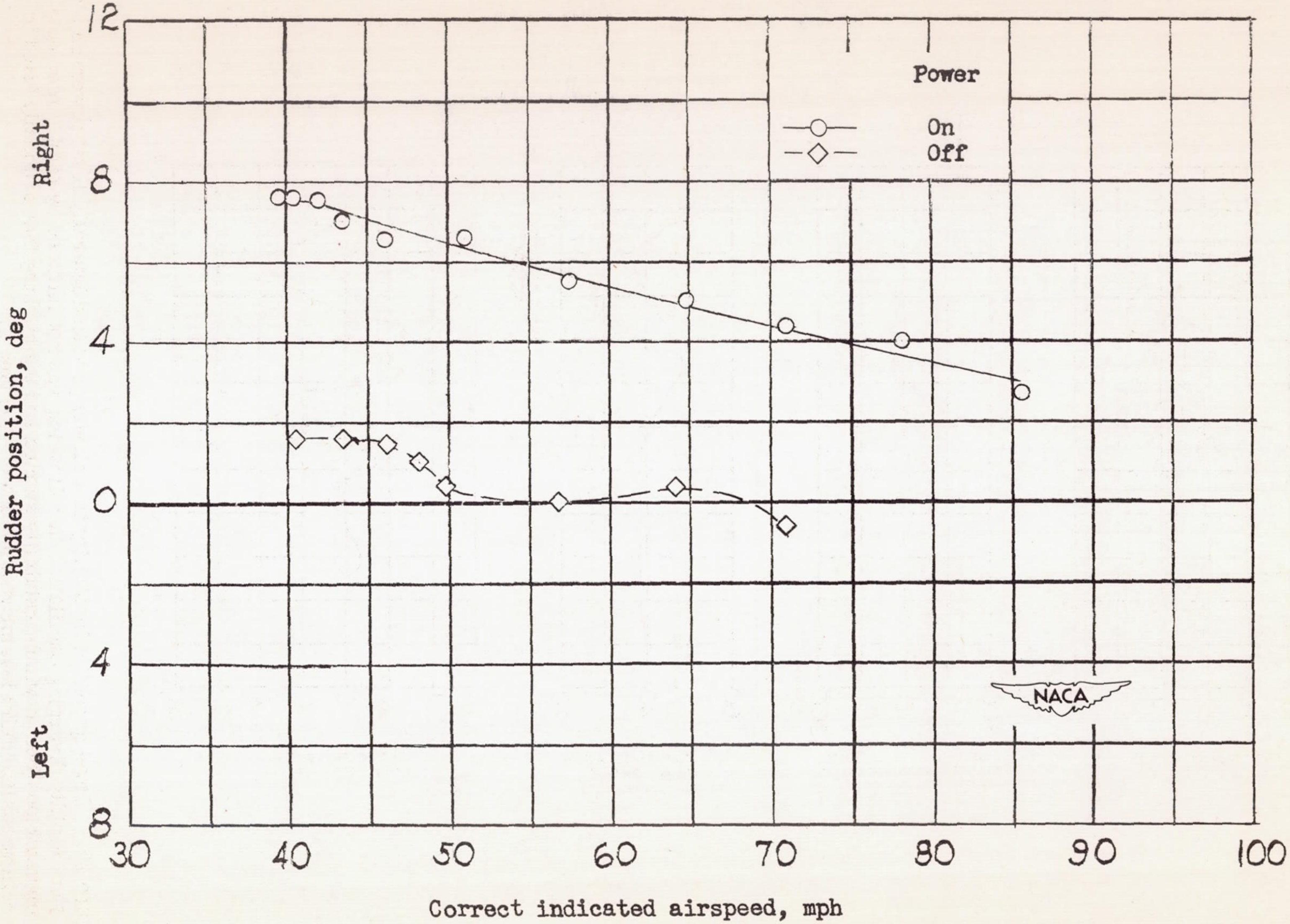


Figure 25.- Rudder positions required for straight unyawed flight at various speeds, power on and off. Elevator tab nose heavy; airplane 1.

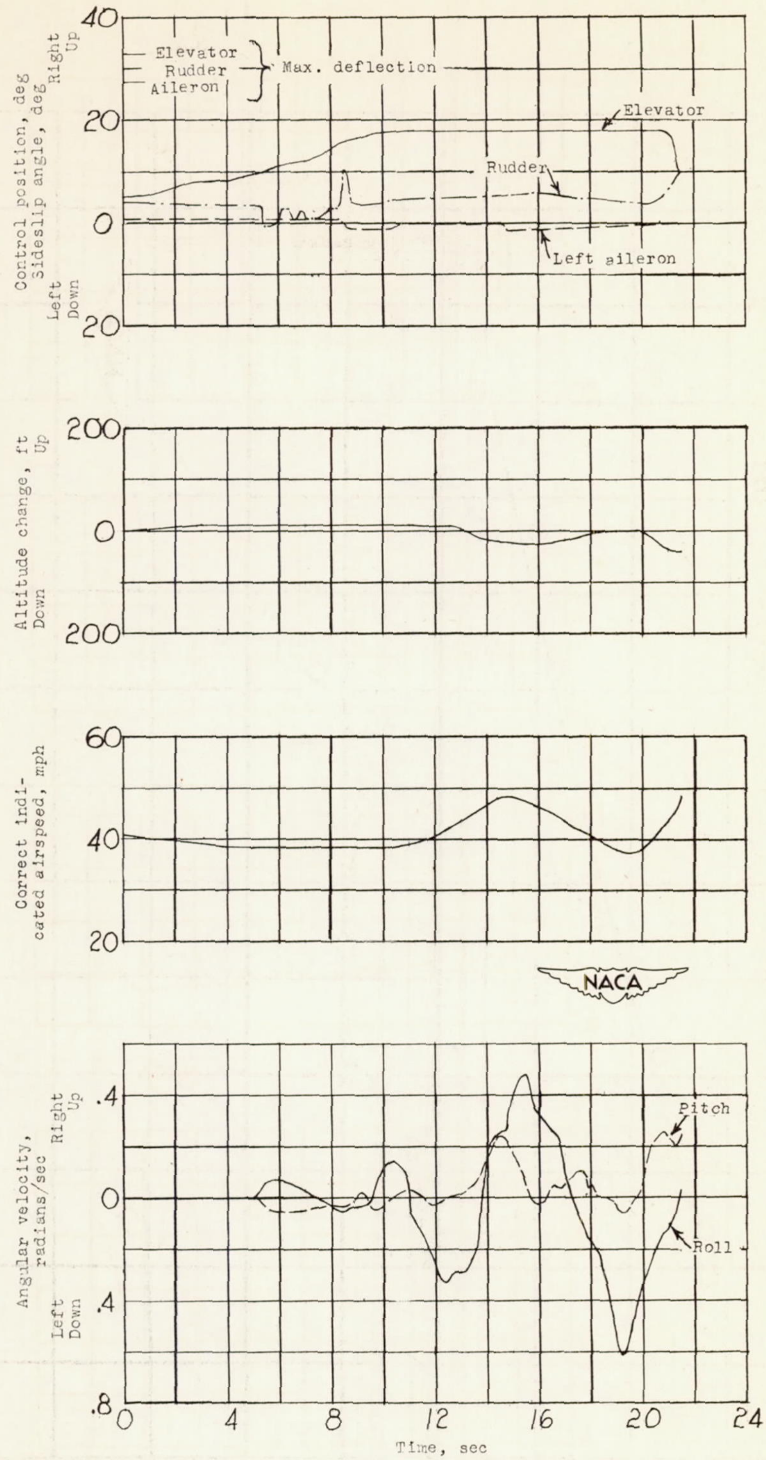


Figure 26.- Development of instability in a slowly produced laterally level power-on stall. Note rapidly diverging oscillation in roll which was not initiated by pilot. Also note the elevator position at which instability started and the pitching that originally tried to relieve stall. Full elevator was not used. Airplane 1.

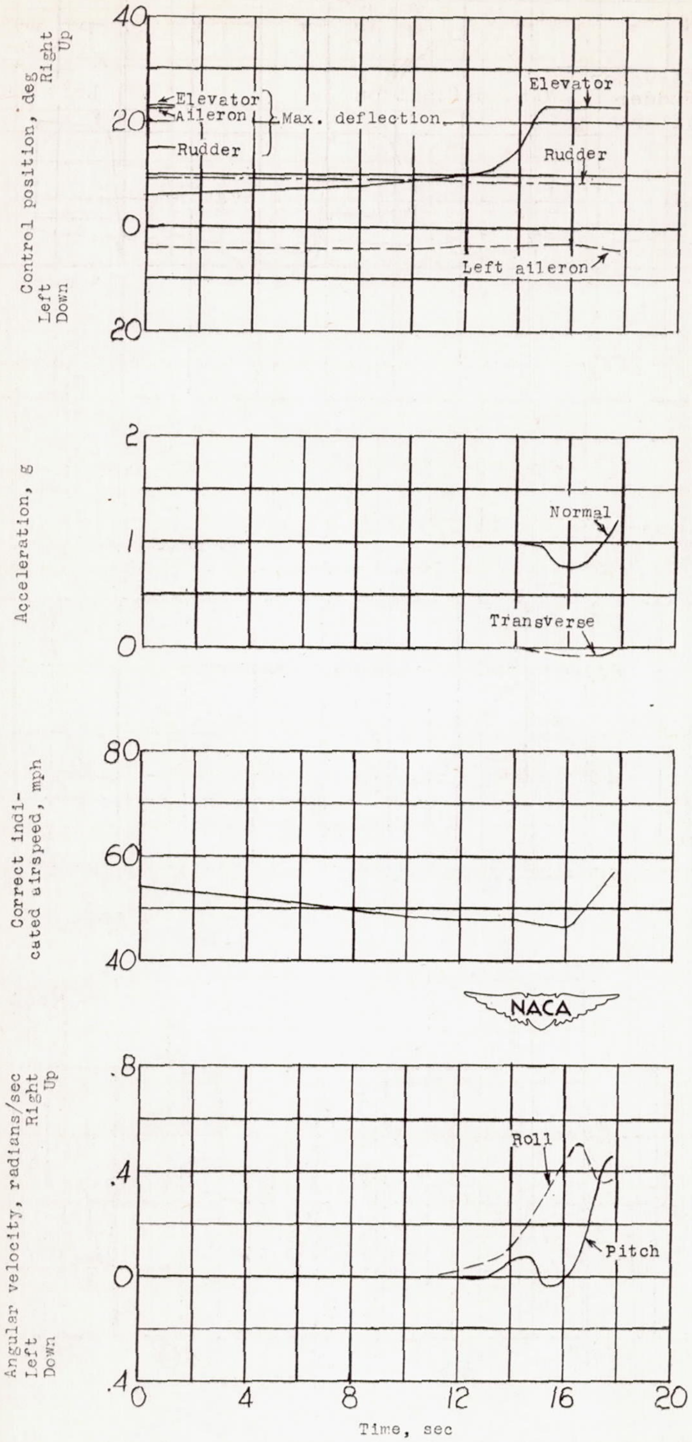


Figure 27.- Power-on stall approach from straight laterally level flight, landing gear up. Elevators were pulled up to their maximum deflection, at which point the resulting unstable motions occurred more abruptly and with somewhat more violence than with elevator held at position for slowly produced stall. Airplane 2.

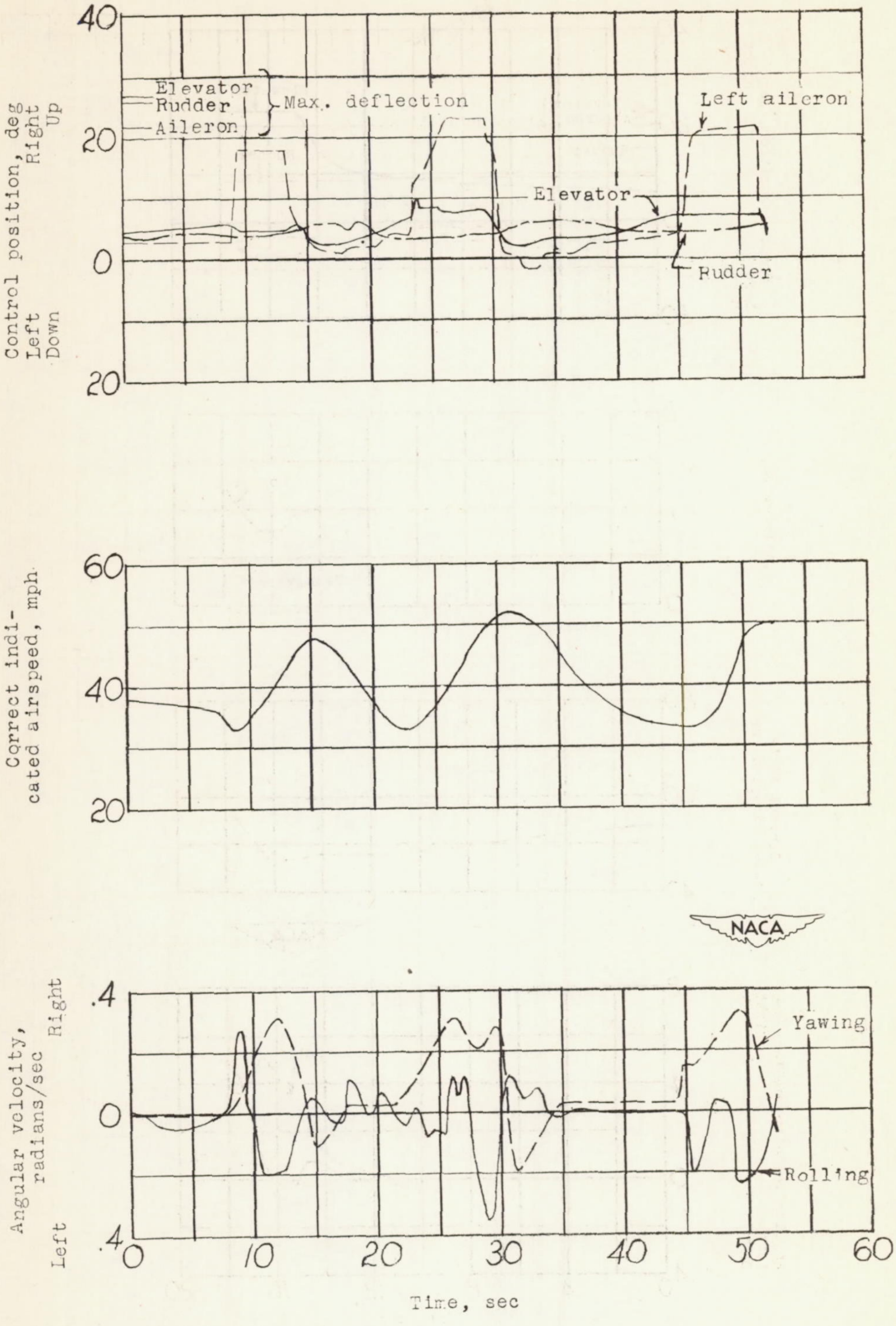


Figure 28.- Power-on stall approach. Elevators moved back until first indication of instability appeared, at which point the ailerons were used. Note the initial correct response in roll followed by a reversal of aileron effectiveness as the effect of adverse yaw predominated. Airplane 5.

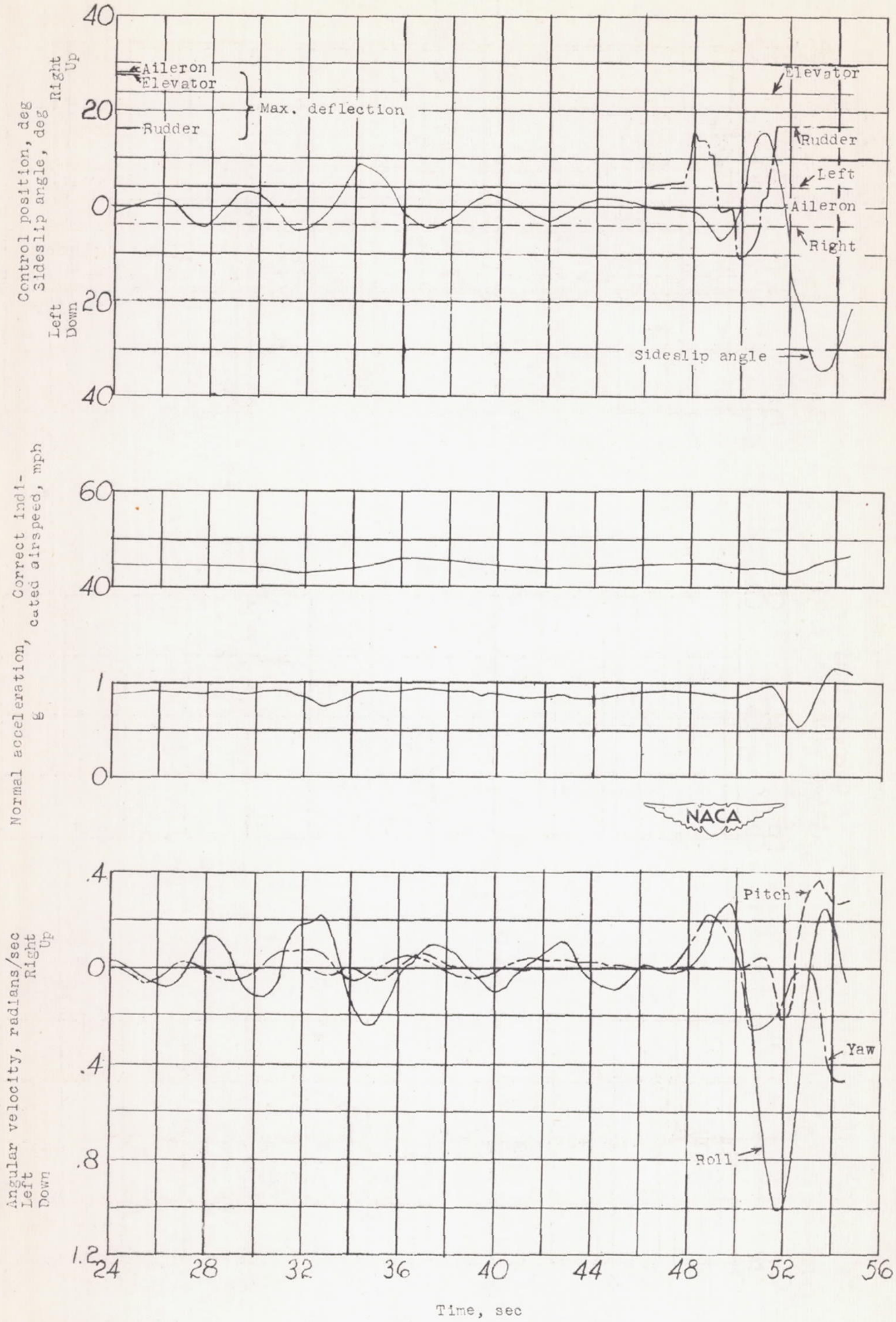


Figure 29.- Response to rudder with stick all the way back. Note continuous oscillation in pitch, roll, and yaw. Also note loss of control following use of rudder. Flaps up; power on; airplane 4.

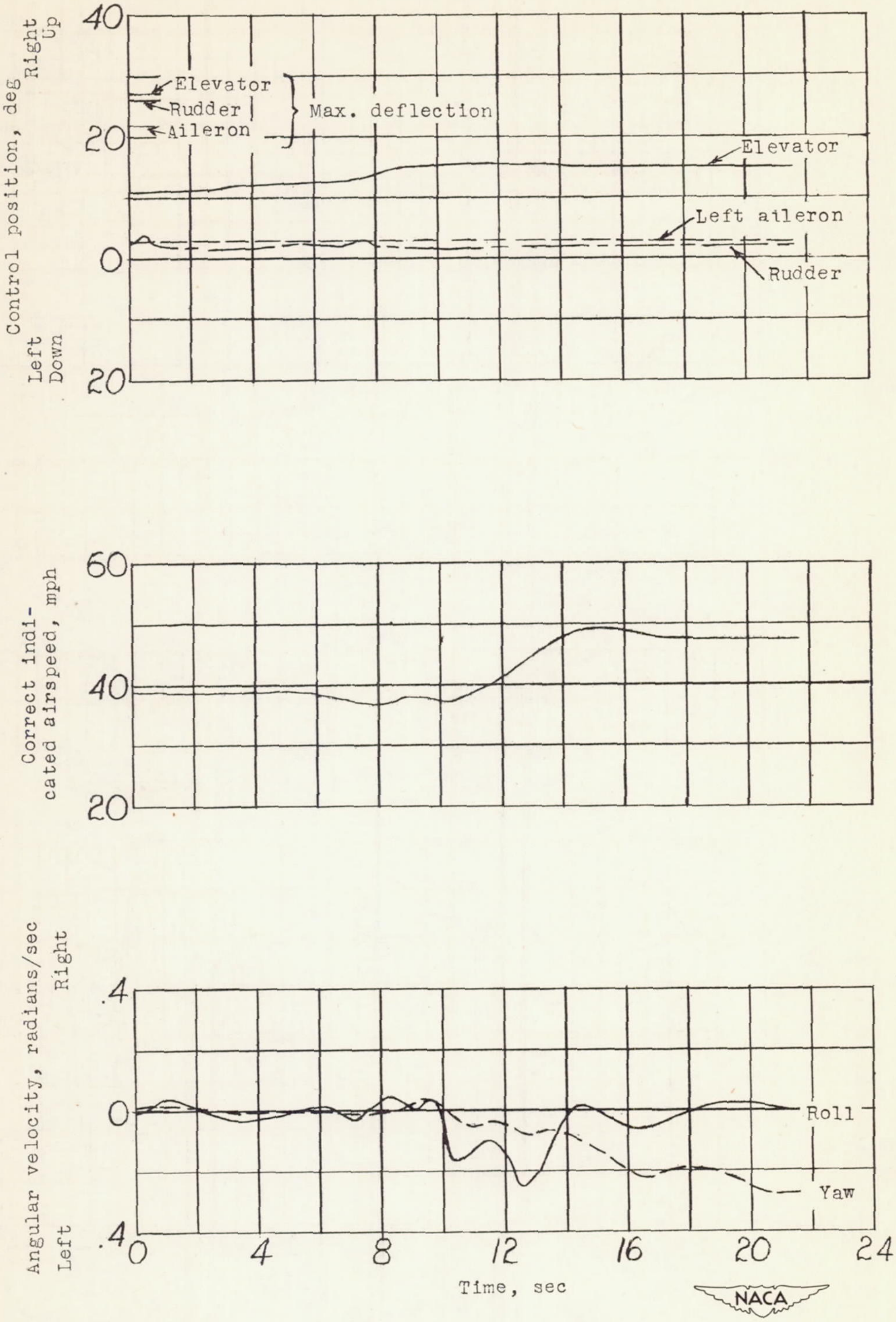


Figure 30.- Power-off stall approach from straight laterally level flight. Elevators were moved back until first indication of instability appeared, at which point all controls were held fixed. Note mild left roll not initiated by pilot which checked itself but resulted in a steady left turn. Airplane 5.

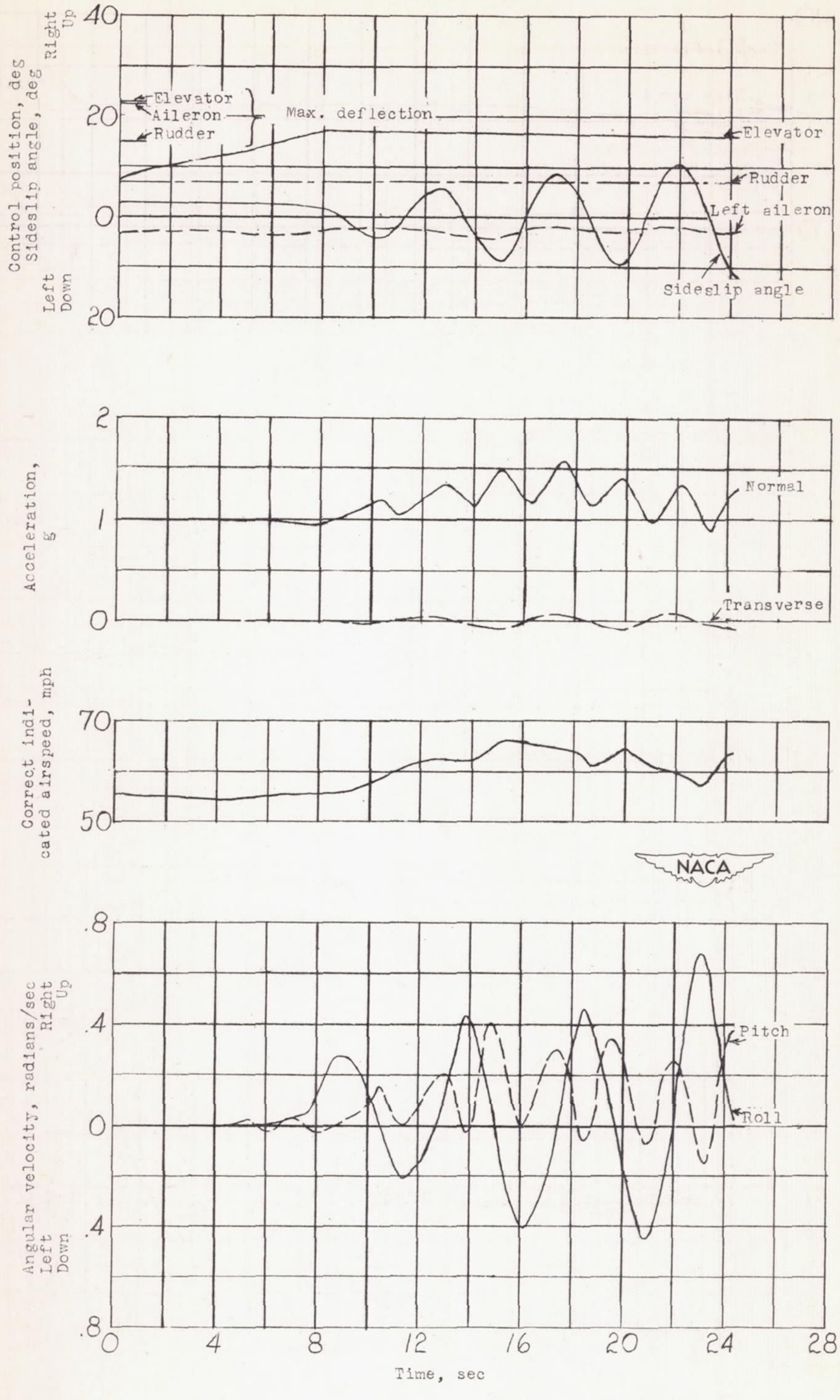


Figure 31.- Power-off stall from straight laterally level flight. When the elevators had been pulled back 3/4 of full deflection, the other controls remaining essentially fixed, the ship developed a falling-leaf motion with increasing oscillations in roll and pitch. Note also the divergent oscillation in yaw as shown by the variation of angle of sideslip with time. Landing gear up; rearward center-of-gravity position; airplane 2.

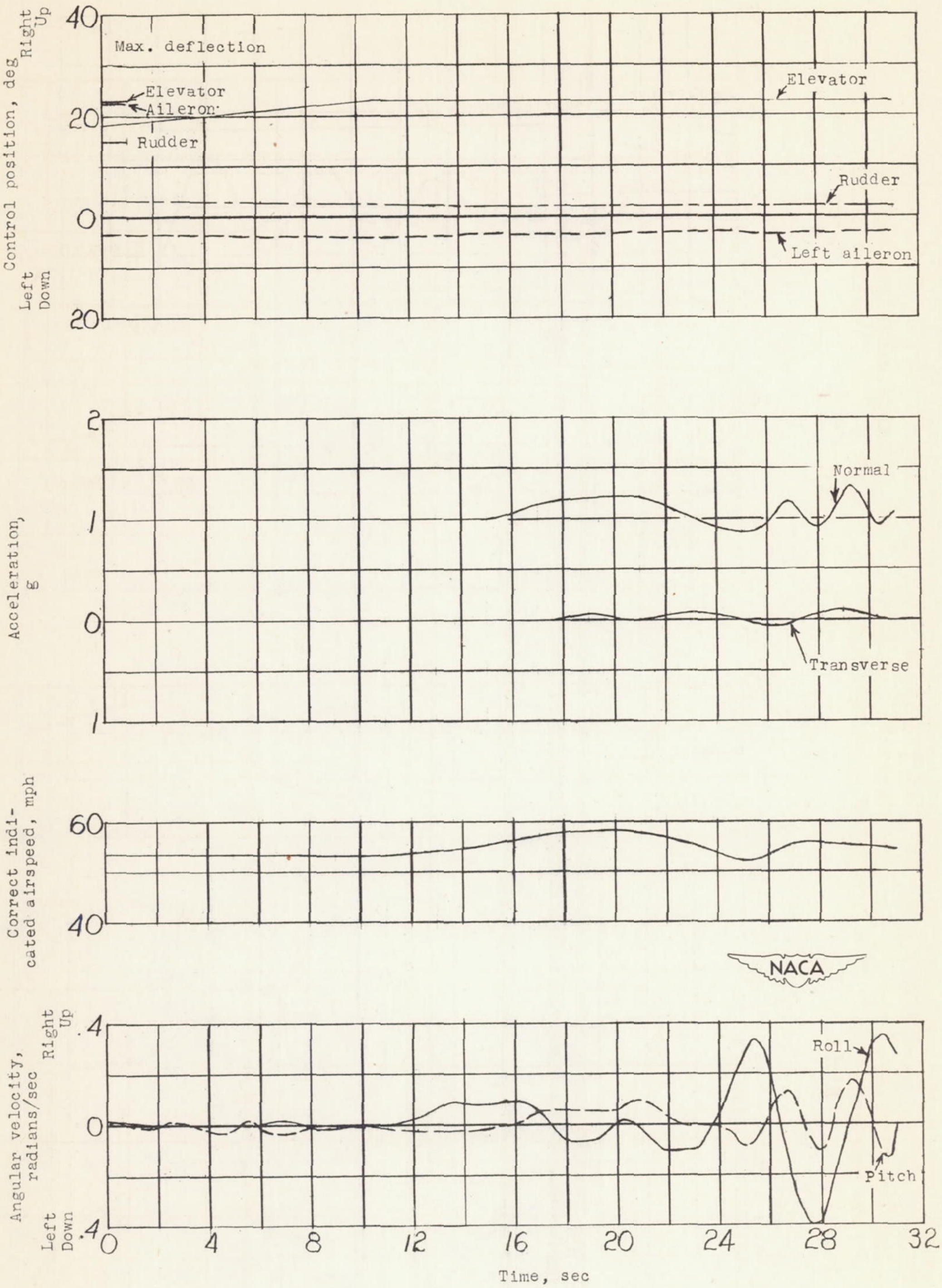


Figure 32.- Power-off stall approach from straight laterally level flight. Elevators were pulled up to their maximum deflections, rudder and ailerons remaining fixed. Note the motions in roll and pitch not initiated by the pilot which slowly increased in magnitude after the elevator had been fully deflected. Landing gear up; forward center-of-gravity position; airplane 2.

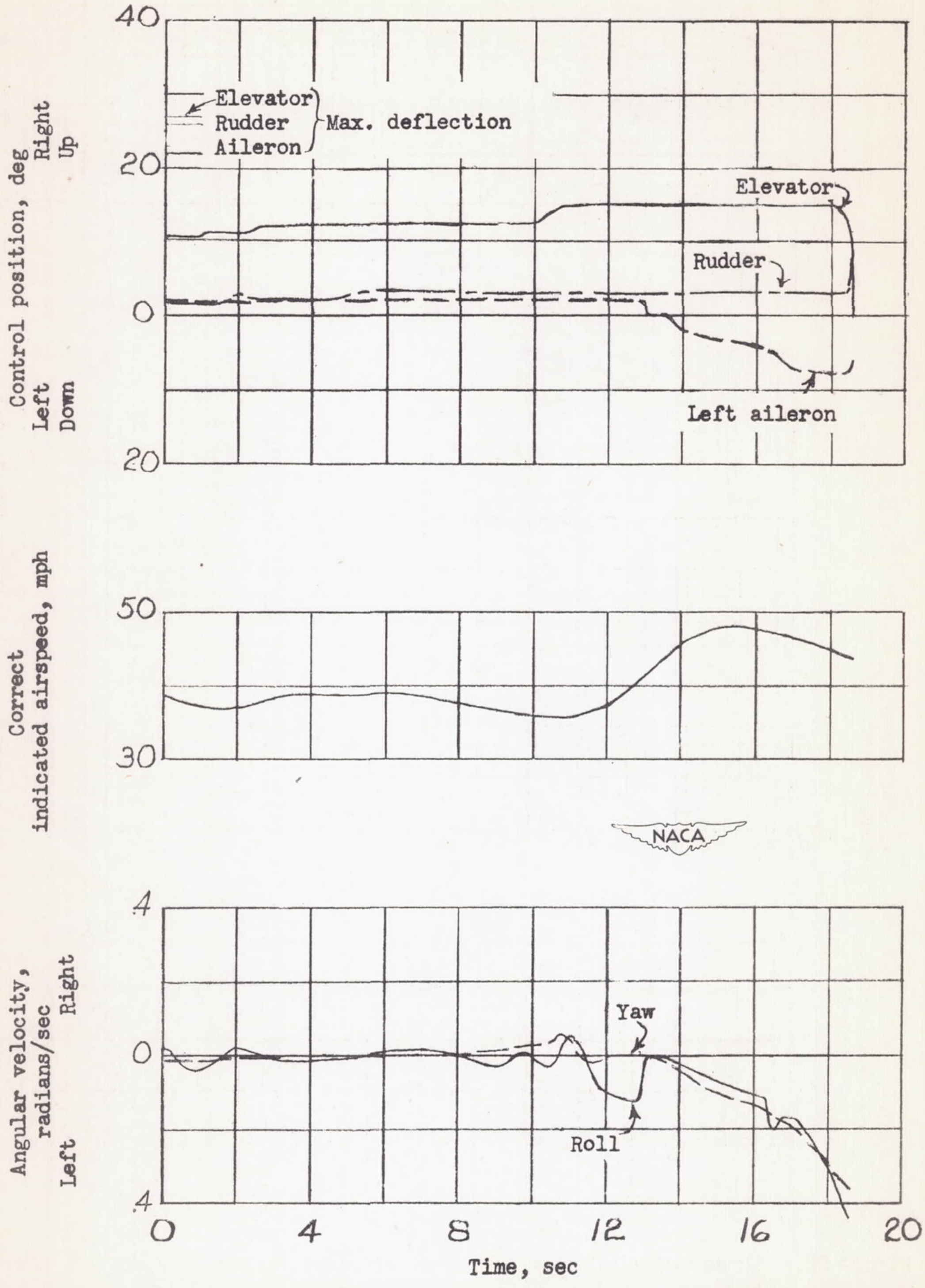


Figure 33.- Power-off stall approach. Elevator moved back until first indication of instability appeared, at which point the ailerons were used. The airplane rolled and yawed left against the applied aileron deflection. Airplane 5.

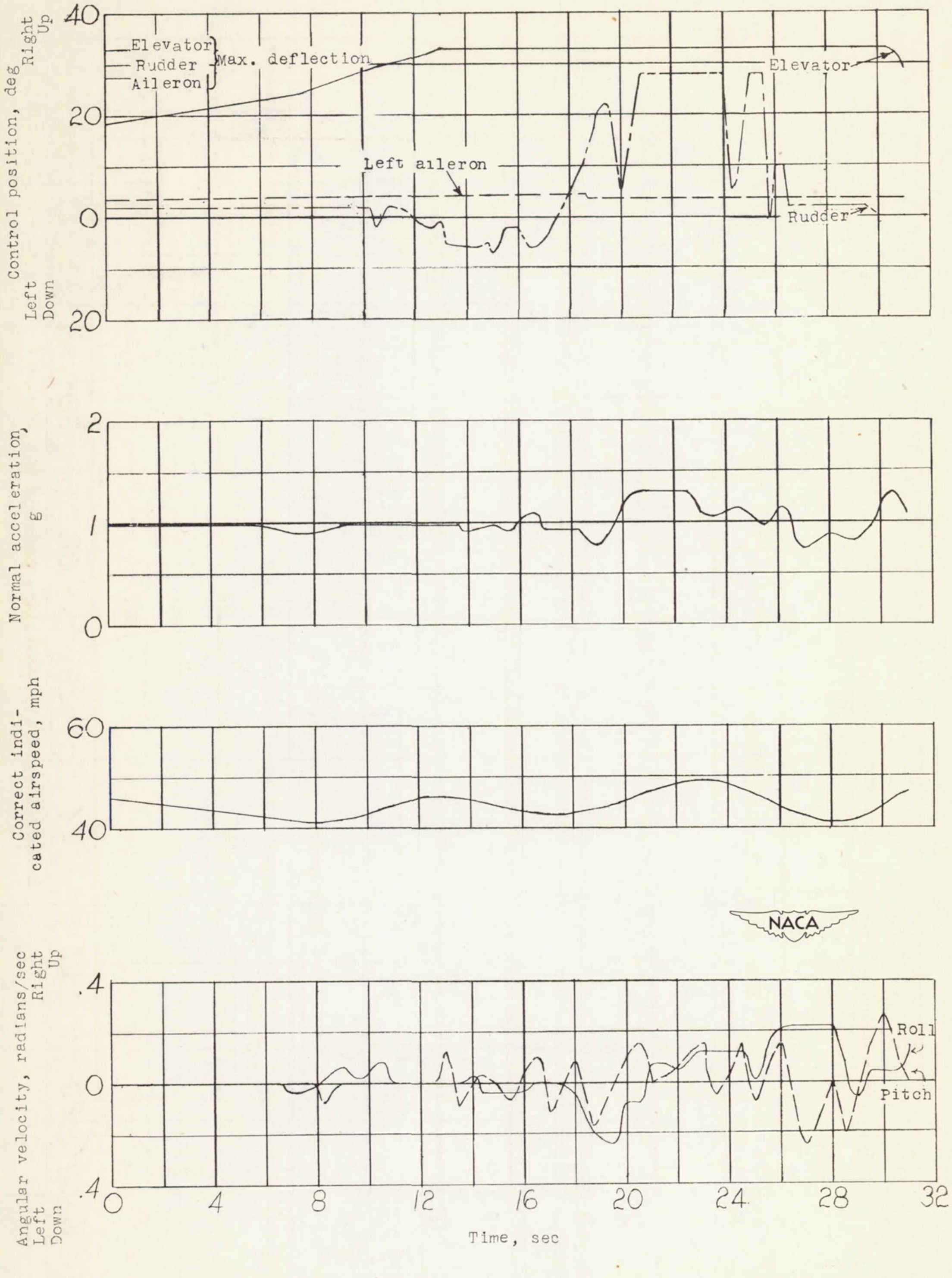


Figure 34.- Flight beyond the stall, power off, using rudder only. Note that pilot can keep violent rolling motion from developing by manipulation of the rudder with the stick all the way back. Airplane 1.

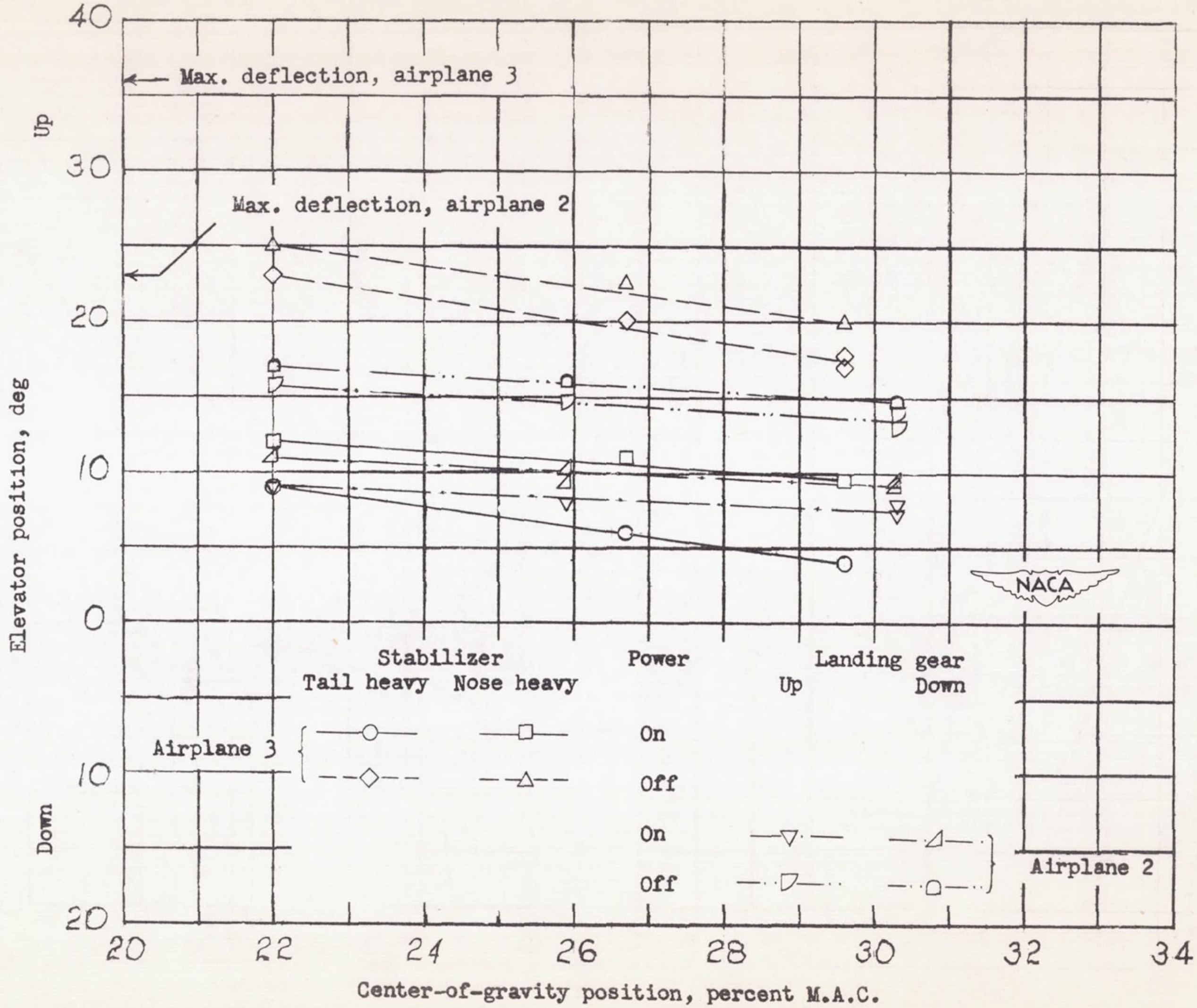


Figure 35.- Elevator positions required to stall at various center-of-gravity positions for different flight configurations. Elevator position measured from thrust axis; airplanes 2 and 3.

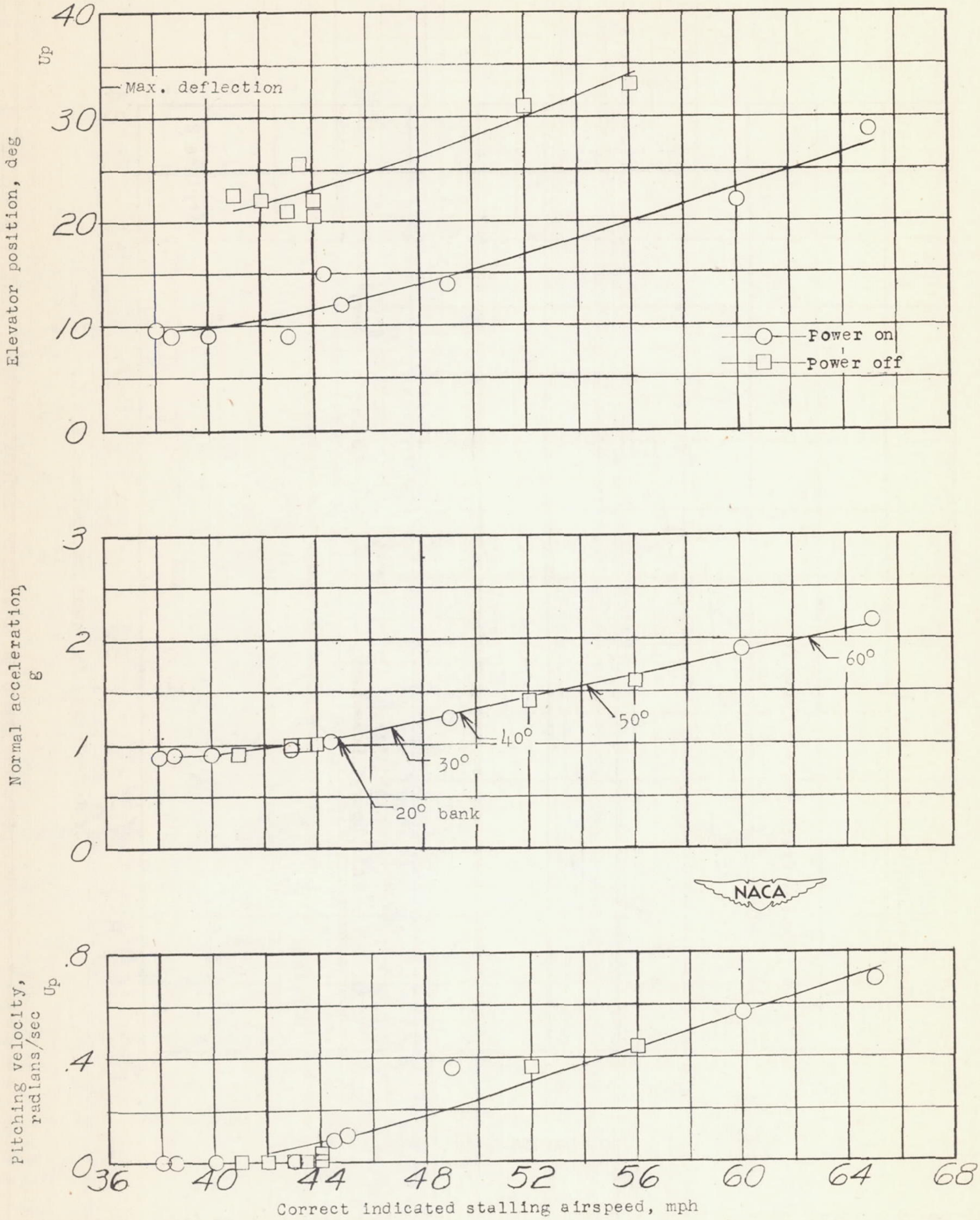


Figure 36.- Variation of elevator position, normal acceleration, and pitching velocity with indicated stalling airspeed in normal banked turns, power on and power off. Elevator position measured from thrust axis; airplane 1.

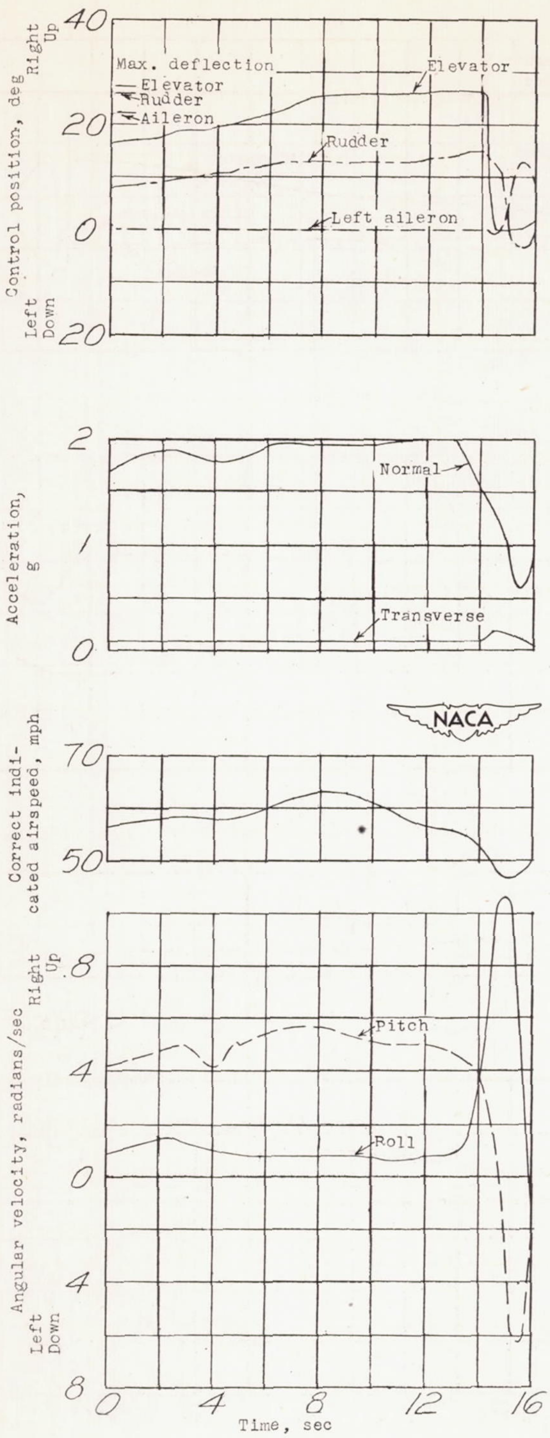


Figure 37.- Stall from a tight power-on left turn. Slipping into turn (as indicated by transverse acceleration) produced roll out of turn when instability occurred. The instability was relieved by moving the elevators down. Airplane 5.

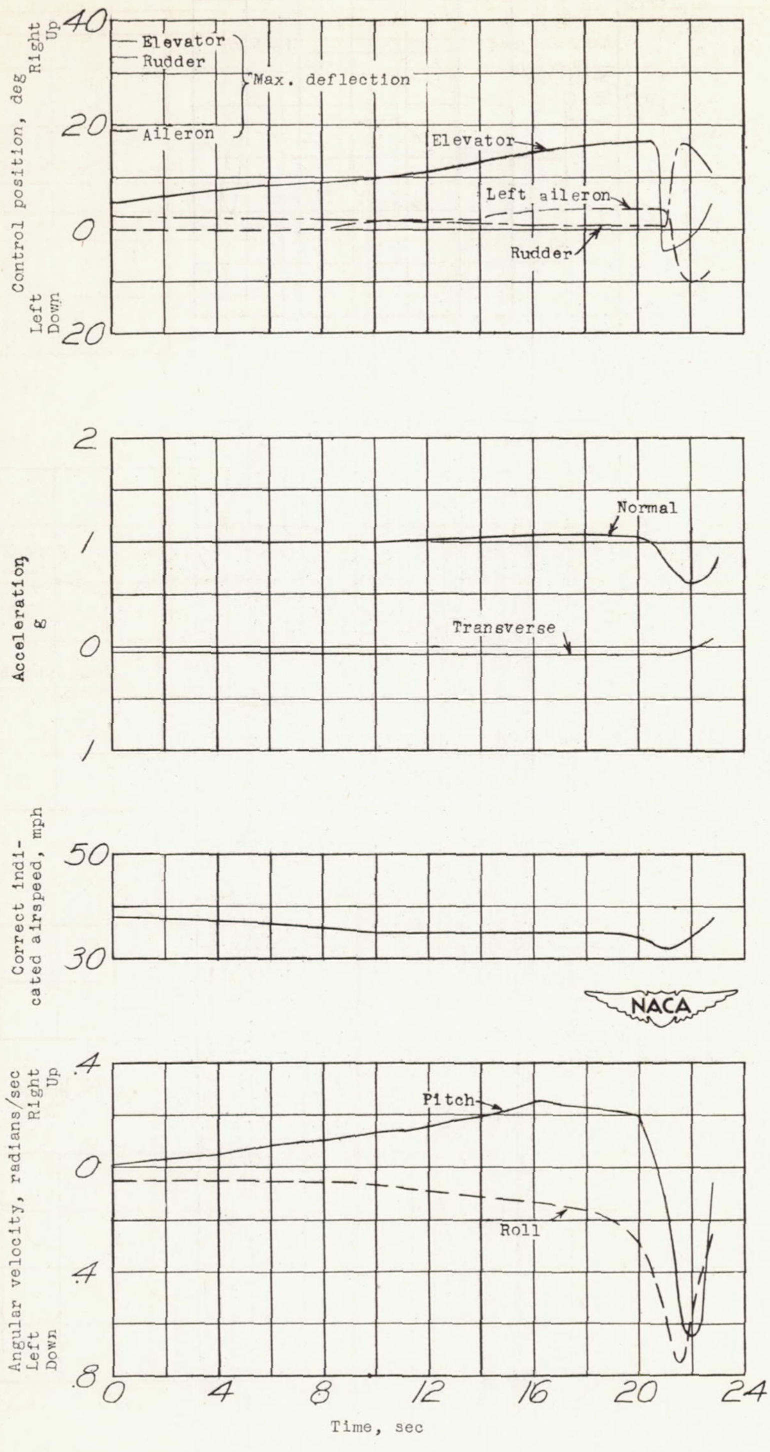


Figure 38.- Stall from a power-on right turn. Note that aileron was held out of the turn and sideslip occurred into the turn. Elevators were slowly pulled up, lateral instability developing at about 16 seconds and resulting in a roll-off out of the turn. Airplane 3.

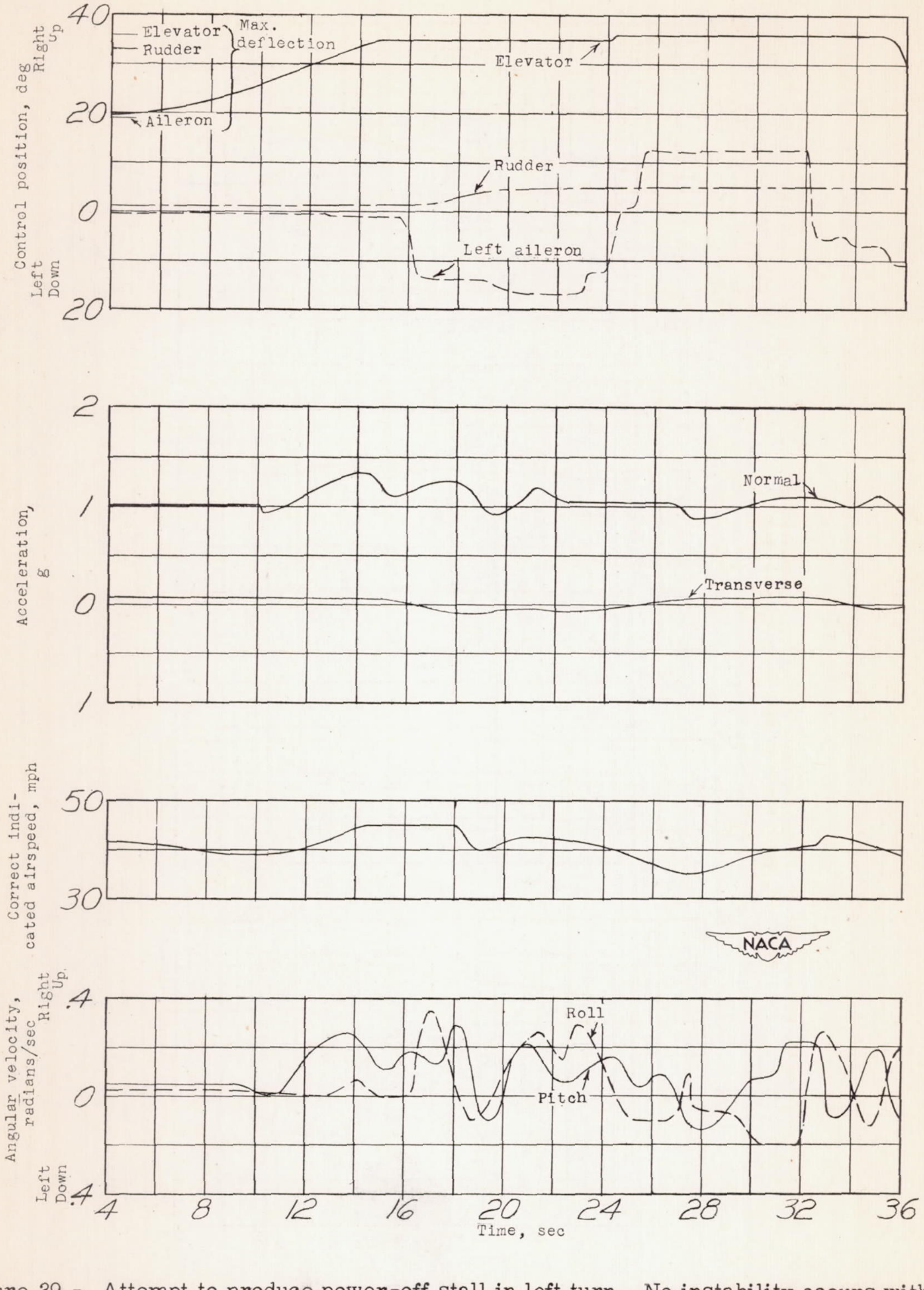


Figure 39.- Attempt to produce power-off stall in left turn. No instability occurs with the elevators full up. Controlled aileron rolls were made to right and left with the elevator remaining fully deflected. Airplane 3.

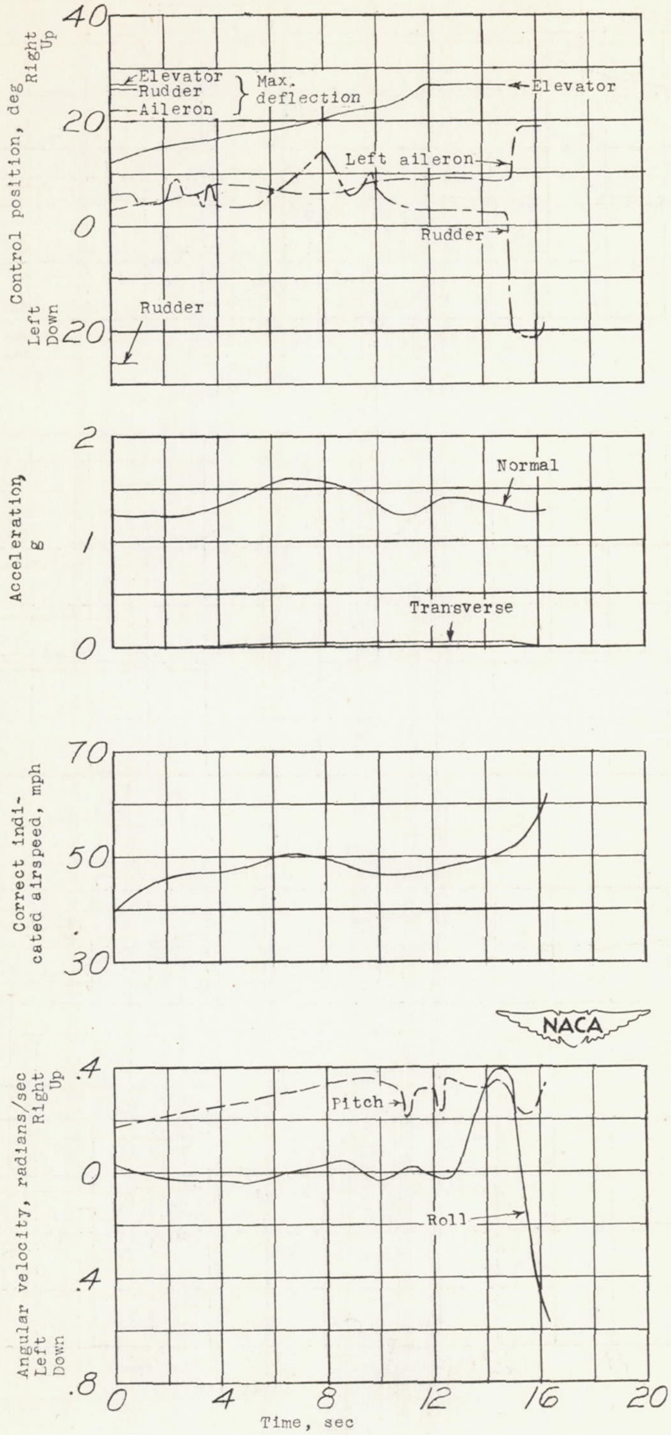


Figure 40.- Stall from a power-off right turn. Transverse acceleration indicates skidding out of turn. As a result, the airplane rolled into turn when instability developed. Note small pitching motions prior to the roll-off which were not initiated by pilot. Airplane 5.

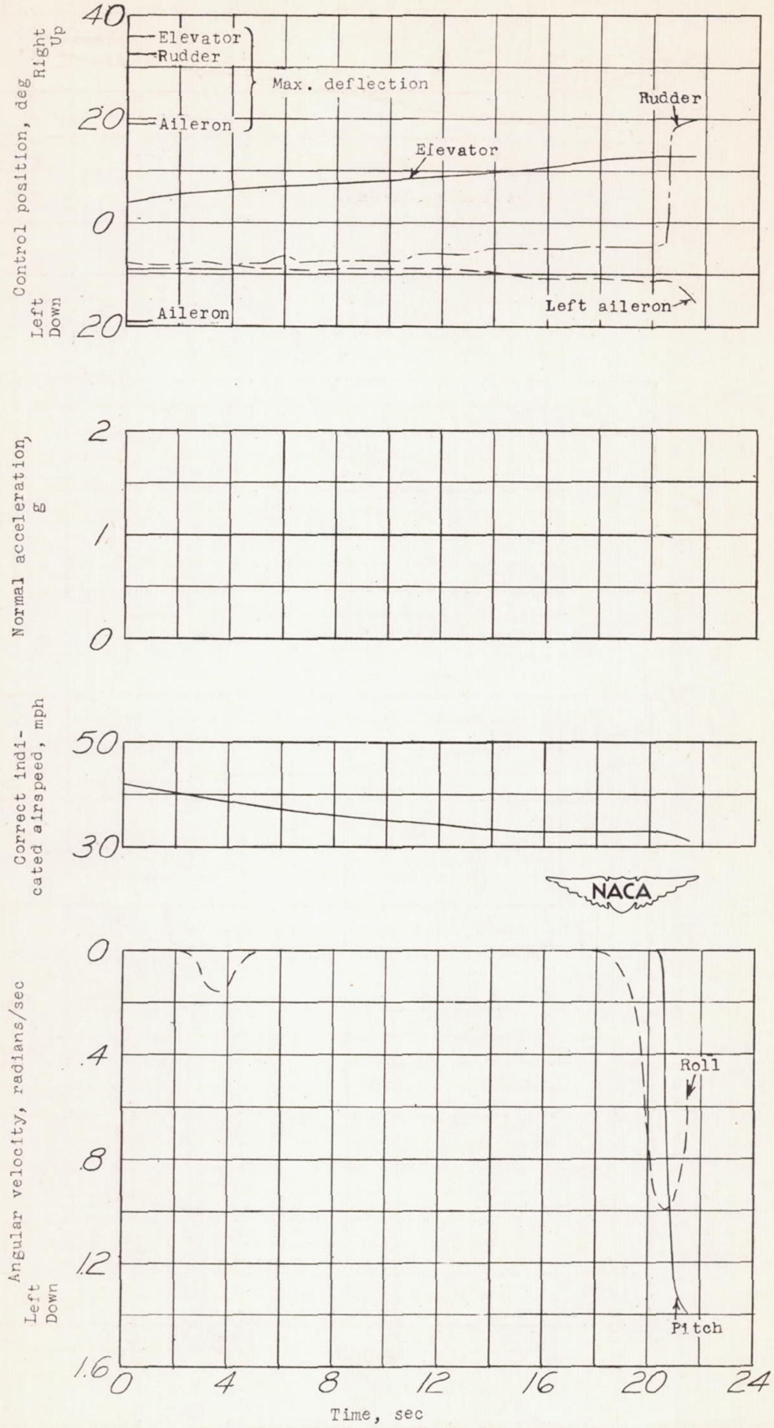


Figure 41.- Stall from a 20° right sideslip with power on. Airplane spun out of sideslip when lateral instability occurred. Note large values of pitching velocity attained. Airplane 3.

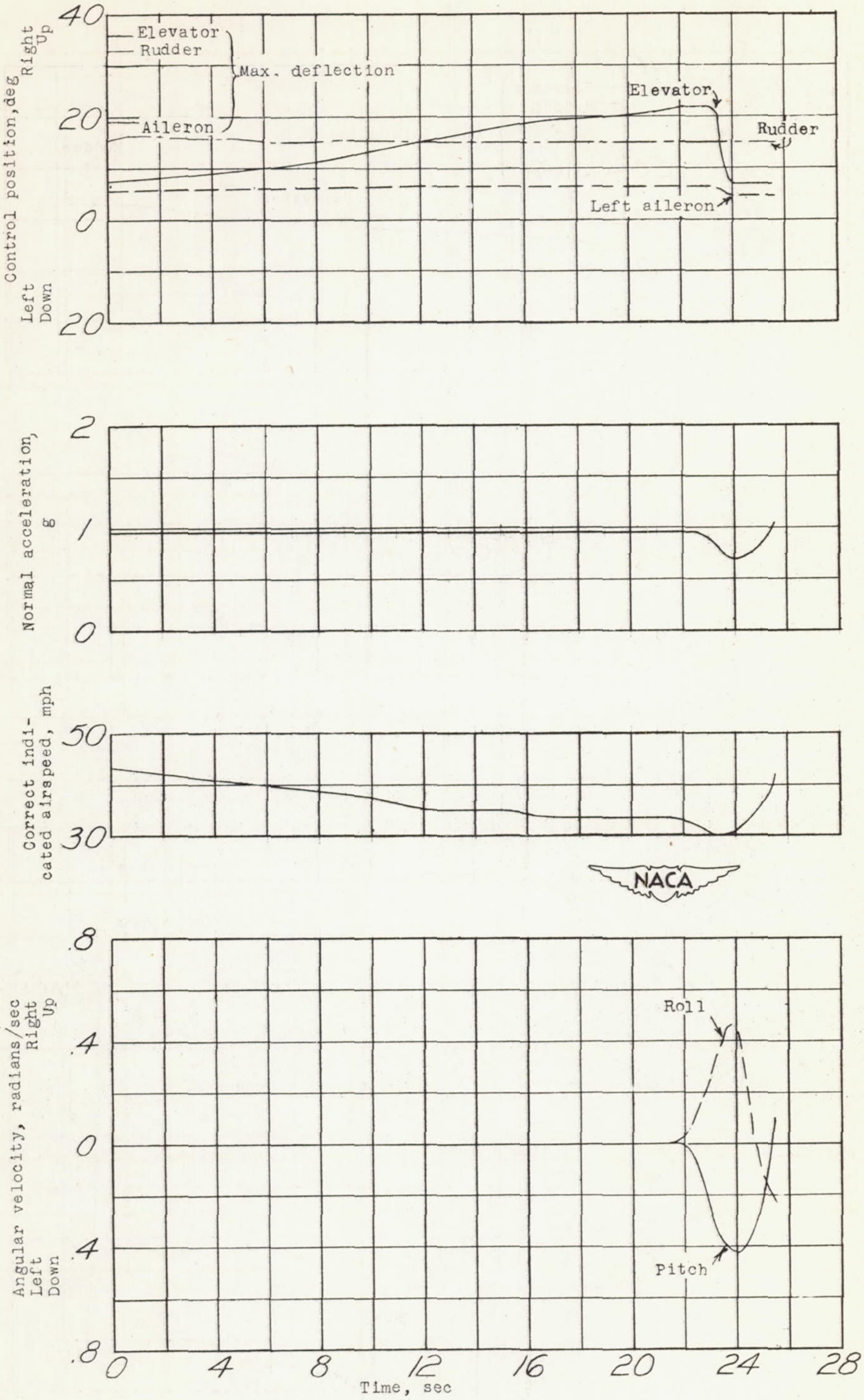


Figure 42.- Stall from a 20° left sideslip with power on. Airplane spun out of sideslip when lateral instability occurred. Instability was checked by pushing the elevators down. Airplane 3.

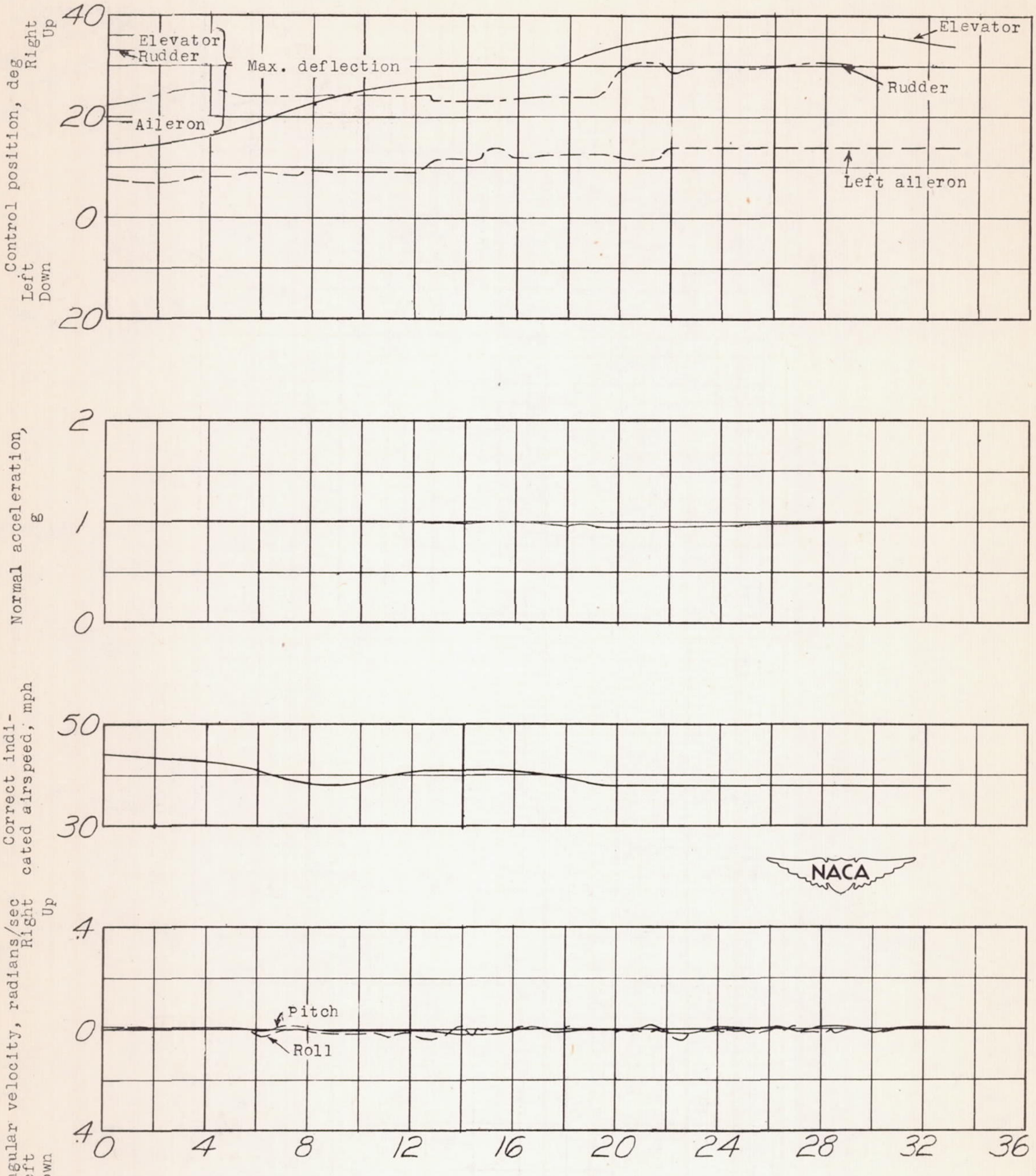


Figure 43.- Attempt to stall from power-off left sideslip. Note that full-up elevator does not produce lateral instability. Airplane 3.

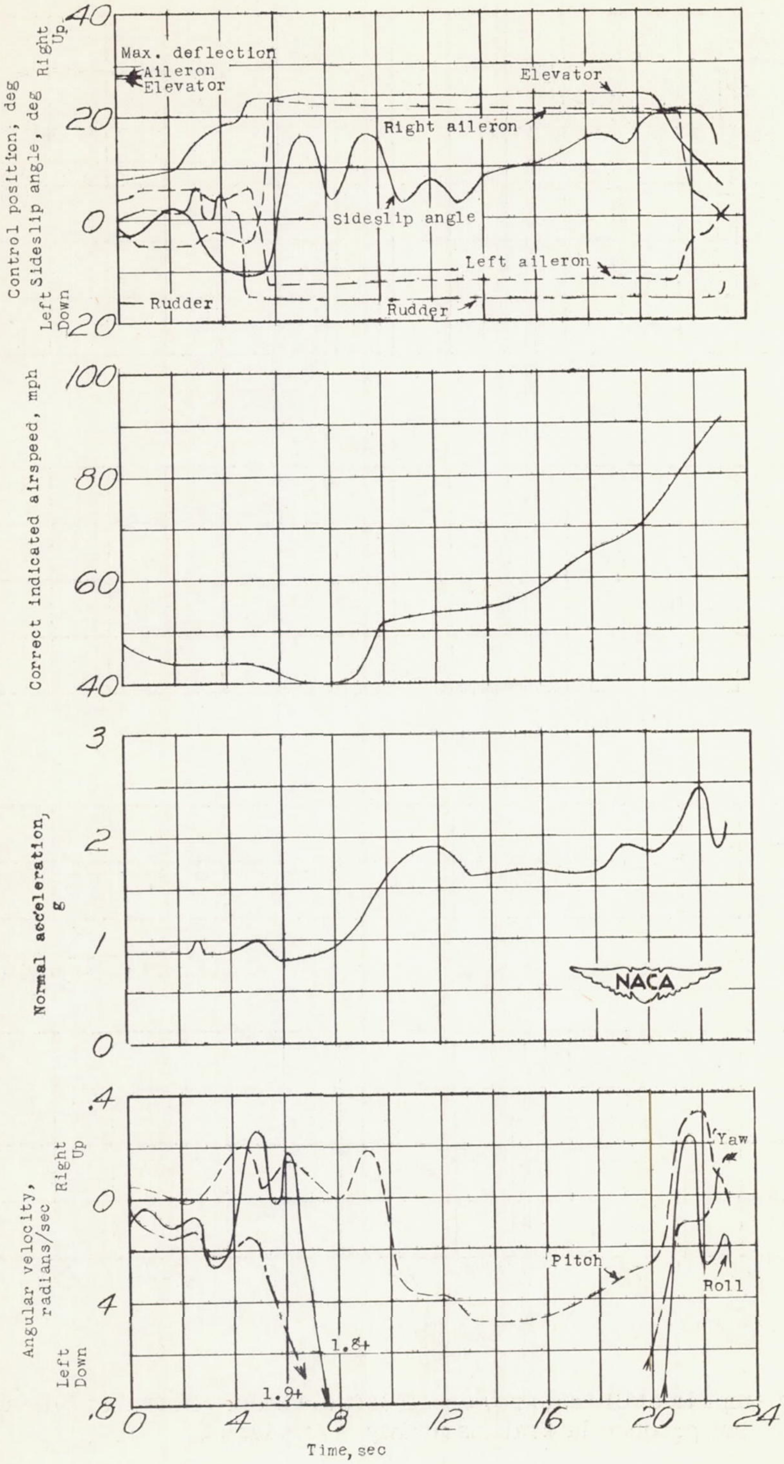


Figure 44.- Time history of entry and recovery from a spin. Flaps up; power on; airplane 4.

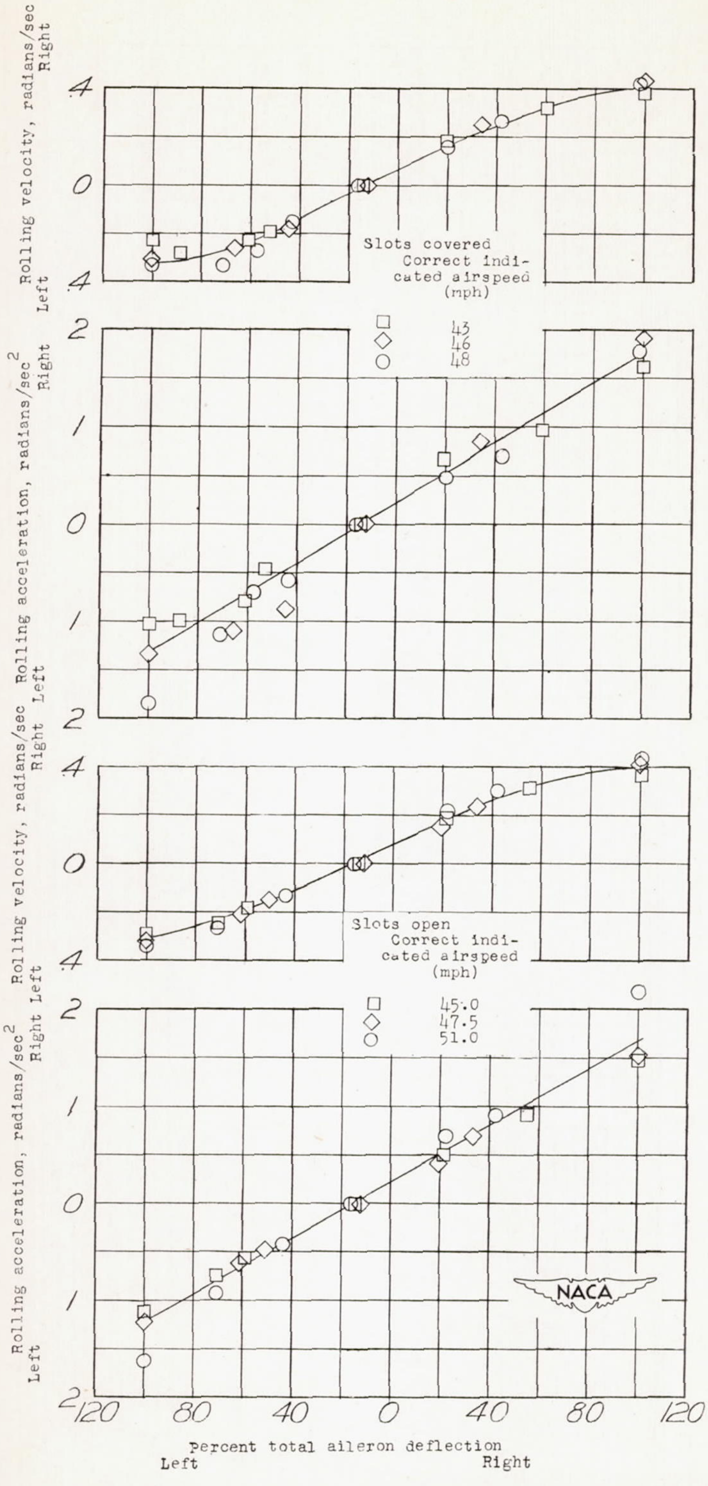


Figure 45.- Effect of slots on aileron characteristics. Airplane 4.