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# RESEARCH MEMORANDUM

# A PRELIMINARY FLIGHT INVESTIGATION OF THE EFFECT OF SNAKING OSCILLATIONS ON THE PILOTS' OPINIONS OF THE FLYING QUALITIES OF A FIGHTER AIRPLANE

By Arnold R. Beckhardt, John A. Harper,
and William L. Alford

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

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## SUMMARY

A preliminary flight investigation of the effect of small-constant-amplitude snaking oscillations on the pilots' opinions of the general flying qualities of a fighter airplane was made. The test airplane, which was equipped with a device for varying the damping in yaw, was a typical high-speed low-wing fighter.

The results showed that, in general, the pilots' perception of the snaking oscillation was mainly dependent on the transverse acceleration which the oscillation produced. As soon as the transverse acceleration during the snaking oscillation reached a value that the pilots could perceive, the oscillation became objectionable from the standpoint of pilot comfort. In this airplane an amplitude of ±0.02g was not always perceptible to the pilot, but on occasion was noticed. An amplitude of ±0.025g was always perceptible and was considered unsatisfactory for a long navigational flight. An amplitude of ±0.08g was considered very unsatisfactory for any mission that this aircraft might perform.

The effect of the snaking oscillation on the efficiency of the airplane as a gun platform and the results of a check on the present service requirements for dynamic lateral directional stability are also discussed. A brief discussion of the design characteristics of the test apparatus used to vary the damping in yaw is also presented.

## INTRODUCTION

Current trends in airplane design which have increased the speed and altitude range usually have had an adverse effect on the lateral oscillatory characteristics of the airplane. In connection with this problem, the NACA has continued with renewed interest a flight-research investigation of the effect of poorly damped lateral oscillations and of small-constant-amplitude snaking or residual oscillations on the pilots' opinions of the general flying qualities of the airplane.

This paper presents some preliminary results obtained with a typical fighter airplane in which by the installation of a small nose fin on the test airplane, the damping in yaw was varied. The nose fin was fitted with a flap which was directly linked to a spring-restrained gyro and hence supplied a force in phase or 180° out of phase with the yawing velocity. By suitable arrangement of the test apparatus this force could be used either to increase or to reduce the damping in yaw of the test airplane.

The majority of the flight tests were made to investigate the effect of a small-constant-amplitude oscillation on the pilots' opinions of the handling qualities of the test airplane. The apparatus was also used to investigate the effect of this constant-amplitude oscillation on the efficiency of the airplane as a gun platform. Inasmuch as the majority of the flights in the test airplane have been made by only two pilots, the results are considered preliminary.

## APPARATUS

### Test Airplane

The airplane used in the tests was a single-place, low-wing, high-speed fighter. A three-view drawing of the airplane is presented in figure 1 and a photograph of the airplane is presented in figure 2. The basic dimensions of the test airplane are given in table I.

### Variable Damping-in-Yaw Control

A preliminary investigation showed that a relatively small vertical fin placed forward of the center of gravity near the nose of the test airplane and oscillated in phase with the yawing velocity would supply sufficient energy, in either a stabilizing or destabilizing direction, to enable the damping-in-yaw characteristics of the test airplane to be varied over a range of practical interest. Oscillation of such a fin would require considerable force, but an analysis showed that a small, aerodynamically balanced flap on a fixed fin could be actuated by direct connection to a rate gyro of the size sometimes used in automatic pilots. In this way the necessity for a servomechanism to actuate the nose fin could be avoided, with a resulting great simplification of the apparatus needed to conduct the tests.

The test airplane was therefore equipped with an auxiliary fin located below the nose of the airplane approximately the same distance from the center of gravity as the airplane's vertical tail. The nose fin had an area equal to approximately 7.3 percent of the area of the vertical tail of the test airplane and was equipped with a flap which was directly linked to a spring-restrained gyro. Photographs of the nose-fin installation are presented in figure 3 and the physical characteristics of the nose fin and gyro are given in table II.

## Discussion of Design Characteristics of the Control

The effect of a gyro-operated fin of the type employed is to supply a moment proportional to the yawing velocity, so long as the yawing velocity is less than the value required to cause the gyro to reach its stops. When the gyro reaches its stops, the moment supplied by the gyro is a maximum. The natural frequency of the gyro was well above the operating range of frequencies of the system.

If the yawing moment due to yawing velocity produced by the fin is unstable and of sufficiently large magnitude, then the yawing moment due to yawing velocity of the airplane will be unstable throughout the range of deflection of the flap. Beyond the range of yawing velocities which cause the gyro to reach its stops, the yawing moment due to yawing velocity of the airplane will be stable. Under these conditions, if an oscillation is initiated at small amplitudes, the oscillation builds up to the point where the flap oscillates between its stops. From this point, the oscillation will reach a constant amplitude. If the airplane is initially displaced to a much larger amplitude than that of the continuous oscillation, the amplitude of the oscillation decreases to that of the continuous oscillation. At very large amplitudes, the damping of the system approaches that of the original airplane. These oscillation characteristics are similar to those of several recent high-speed airplanes which experience so-called snaking or residual oscillations.

The spring restraint on the gyro could be supplied either by the aerodynamic hinge moments on the flap or by a pair of restoring springs such as shown in figure 3(b). The aerodynamic moment provides a restoring tendency which increases as the dynamic pressure increases. The magnitude of the damping-in-yaw derivative $C_{n_r}$ supplied by the device with this type of restraint decreases with increasing speed. With a mechanical spring restraint, however, the magnitude of $C_{n_r}$ supplied by the device increases with increasing speed. By combination of these two effects, the value of $C_{n_r}$ provided by the device could be maintained fairly constant over a reasonable speed range.

By reducing the restoring tendency of the flap to zero, the flap could be arranged to supply a constant moment opposing the yawing velocity. The effect of this moment in damping the lateral oscillations would be similar to that of static friction in the system. Other unusual effects might be obtained by use of an overbalanced flap or one with nonlinear hinge-moment characteristics. Some brief tests of arrangements of this kind were made in the process of initially adjusting the device, but detailed investigations of these effects were not conducted because of lack of time.

It should be noted that the gyro is sensitive to angular velocity about an axis normal to the gyro spin axis and the gimbal axis. This axis is fixed with respect to the airplane and, for the present tests, was a vertical axis normal to the fuselage reference line. Stability derivatives, however, are ordinarily defined with respect to stability axes, which have the vertical axis normal to the relative wind. The gyro therefore measures components of rolling as well as yawing velocity when the angle of attack is not zero. For the present tests, which were conducted in high-speed flight on an airplane with small effective dihedral, the effect of this rolling-velocity component may be neglected. On an airplane with high dihedral effect in flight at high angle of attack, however, the rolling velocity measured by a gyro of this type may be as large as the yawing velocity, and the effect of the rolling velocity should be taken into account in calculating the effect of the gyro on the damping of the lateral oscillations.

## Instrumentation

Standard NACA recording instruments were used to measure the following quantities: indicated airspeed, pressure altitude, control positions, flap position, flap hinge moment, and the airplane's sideslip angle, yaw angle, rolling velocity, yawing velocity, and normal, transverse, and longitudinal accelerations. The airspeed and altitude measurements were made with a Kollsman high-speed pitot-static tube mounted approximately one maximum fuselage diameter ahead of the nose. Calibration of a similar airspeed installation on the same type of airplane as the test airplane indicated that this type of installation gives airspeed measurements which are $2\frac{1}{2}$ percent low. Airspeed as used in this paper is indicated airspeed and is not corrected for this position error. A recording sideslip vane was mounted on a boom located on the right wing tip. Changes in sideslip angle are believed to be correct but the exact magnitude is in slight error due to angularity of flow at the sideslip vane. The error $\left(\text{approx. } 1\frac{1}{2}^\circ\right)$ is independent of sideslip angle.

## FLIGHT TESTS

The results of this preliminary investigation are based on a series of 19 flights, the majority of which were made by two pilots. During the first flights of the test airplane, hinge-moment measurements showed that the flap was slightly overbalanced. This overbalance resulted in the flap moving between its stops approximately in phase with the angle of yaw. If the direction of rotation of the gyro rotor was that which should increase the damping in yaw, this condition resulted unexpectedly in an oscillation which had less damping and a shorter period than the original airplane. If the direction of rotation of the gyro rotor was unstable, an oscillation which had increased damping and a longer period compared to that of the original airplane resulted. Two flights were then made with the flap neutrally balanced and with this arrangement a constant-amplitude oscillation was produced.

Trailing-edge strips consisting of two 0.035-inch-diameter steel rods covered with scotch tape were then installed and the remaining flights were made with the flap slightly underbalanced. With the trailing-edge strips installed the flap had a tendency to float with the relative wind. The nose flap moves approximately in phase with the yawing velocity for this condition. It should be pointed out that in the frequency range covered in these tests any moments due to inertia or friction which tended to produce phase lag between the flap deflection and the yawing velocity in an oscillation were largely cancelled out by the hinge moment due to angle of yaw and the resulting motion of the flap had approximately the desired phase relationship with the yawing velocity.

Changes in the frequency of the constant-amplitude oscillation from about 0.25 cycle per second to 1.0 cycle per second were obtained by varying the airspeed from about 140 miles per hour to 550 miles per hour. Changes in the amplitude of the constant-amplitude oscillations from about $\pm 1.25^{\circ}$ of sideslip to $\pm 2.50^{\circ}$ were obtained by varying the altitude of the tests from 3,000 feet to 30,000 feet.

The maneuvers performed with the test airplane were as follows:

(1) Abrupt rudder kick: The pilot abruptly deflected and returned the rudder to neutral while holding the stick fixed. A typical time history of the motion of the airplane and control surfaces following an abrupt rudder kick for the airplane with the nose-fin gyro on and off is presented in figure 4.

(2) Abrupt rudder kick followed by corrective rudder: In these maneuvers, the airplane was allowed to reach a constant-amplitude condition after the rudder kick and then the pilot applied corrective

rudder to damp the oscillation. The oscillation was then allowed to build up to a constant-amplitude condition again. A typical time history of this maneuver is presented in figure 5.

(3) Strafing runs: These runs were made in a shallow dive from approximately 10,000 feet to sea level with the indicated airspeed varying from approximately 250 miles per hour to 500 miles per hour. A series of three runs were made during each flight; one with the nose-fin gyro off using the fixed gun sight, and then with the nose-fin gyro turned on, runs were repeated using the fixed sight and a K-14B gyro-computing sight. A time history of a strafing run is presented in figure 6.

Several flights were made with the nose-fin gyro used to increase the damping in yaw of the test airplane. A typical time history of the motion of the test airplane following an abrupt rudder kick for this condition is presented in figure 7.

## BASIS OF PILOTS' OPINIONS

After each flight the pilot reported a description of the flight with particular emphasis on his over-all reaction to the effect of the snaking oscillation on his opinion of the general flying qualities of the aircraft. These opinions were based on the pilot's sense of comfort and on his reaction to the effect of such an oscillation on his efficiency in performing a typical maneuver such as a strafing run. By use of the larger amplitude oscillations which occurred after the abrupt rudder kick (fig. 4) a check was made on the present period-damping requirements for the dynamic directional-lateral oscillation of references 1 and 2.

The pilot was asked to rate each maneuver with one of the following:

(1) Unsatisfactory: Conditions which might be dangerous under certain flight conditions or which are tiring and definitely unpleasant in normal flight operations.

(2) Tolerable: Conditions which are not necessarily dangerous or tiring but which are unpleasant.

(3) Satisfactory: Conditions which are both safe and pleasant.

## RESULTS AND DISCUSSION

### Tolerable Limit of Snaking Oscillations

A survey of the flight records made in smooth air in simulated cruising flight where visual reference was rather obscure, has indicated that the pilots' perception of the small-constant-amplitude snaking oscillation is mainly dependent on the transverse acceleration which the oscillation produces. The small-amplitude oscillations developed in these tests were not noticed at low speeds where they produced low values of the transverse acceleration, but these same amplitude oscillations became very unsatisfactory at high speeds where larger values of transverse acceleration were produced.

During these runs the pilot's field of vision was not restricted in any manner but he was not referring to any direct visual reference; that is, he was not looking at the reticle of a gunsight or observing fluctuations in the directional gyro, or observing a fixed spot on the horizon.

As soon as the transverse acceleration during the snaking oscillation reached a value that the pilots could perceive, the oscillation became objectionable from the standpoint of pilot comfort. An amplitude of acceleration of ±0.02g was not always perceptible to the pilot but on occasion was noticed. An amplitude of ±0.025g was always perceptible and was considered unsatisfactory for a long navigational flight. An amplitude of ±0.08g was considered very unsatisfactory for any mission that this aircraft might perform.

It should be noted that the values of transverse acceleration used in these limits are the computed values of linear acceleration at the pilot. These values were computed by combining vectorially the linear acceleration at the pilot due to angular acceleration and the measured value of transverse acceleration. The values of angular acceleration were obtained from the slope of the angular velocity curves plotted against time. In this airplane the pilot is located approximately 30 inches ahead of the center of gravity but calculations based on the experimentally determined linear and angular accelerations indicate that little change in the amplitude of the linear acceleration at the pilot occurs as the pilot's position changes from the center of gravity to the nose.

### Effect of Snaking Oscillation on Gun-Platform Characteristics

The effect of this small-amplitude oscillation on the efficiency of the test airplane as a gun platform was determined by taking gun-camera pictures of a fixed ground target during high-speed strafing runs. A time history of a strafing run is presented in figure 6 and the results of a series of these strafing runs made in smooth and moderately rough air are presented in figure 8. The maximum variation in normal acceleration during the smooth-air runs was approximately ±0.12g. During the rough-air runs the maximum variation was approximately ±0.40g. Figure 8 is presented as the percent of the total run time the pilot kept the airplane's line of sight within horizontal angular increments of $0.10^{\circ}$ from the target. This angular deviation is the horizontal angle between the thrust axis of the airplane and the line of sight from the gun camera to the target.

The results presented in figure 8 do not represent any ordnance-distribution pattern but they do give an indication of the relative effectiveness of the airplane as a gun platform. It would be expected that an increase in the scatter of the line of sight would also increase the scatter of any gun fire from the airplane. Because of the statistical nature of this type of data, conclusions made from data obtained in these tests should be viewed with caution. Due to lack of time, only a limited number of these strafing runs were made and a more complete survey of a greater number of pilots is necessary before definite conclusions concerning the effect of small-constant-amplitude oscillations on the accuracy of gun fire from an airplane can be made. It would be desirable to conduct these tests with actual gun firing from the airplane.

The results of these limited tests indicate that in smooth air the small-amplitude oscillation reduces the effectiveness of the airplane as a gun platform with either a fixed gun sight or a computing gun sight. In moderately rough air, there is no apparent effect of the snaking oscillation on the effectiveness of the airplane as a gun platform.

An analysis of the tracking errors of a fighter airplane attacking a fixed target on the ground is presented in reference 3. This reference includes a comparison of the tracking errors of a typical gyro-computing sight and a fixed-reticle type of sight.

The analysis shows that the tracking errors between gunsight and target tend to be smaller in the case of the gyro sight since the smoothing function of the sight tends to stabilize the reticle in spite of airplane and pilot irregularities. During the strafing run, the pilot's chief reference for corrective controls is the position of the reticle in the gun sight with respect to the target. If the effect of the airplane's motion would not be as apparent when sighting through a gyro type of sight because of the smoothing process inherent in this type of sight, the pilot would not attempt to apply as much corrective rudder to keep the airplane on the target. It may be reasoned that this smoothing process in the gyro sight will increase the scatter of the bullets due to the snaking oscillation if the airplane is performing a small-constant-amplitude oscillation with a frequency that the pilot could control with concentration. Figure 8 indicates that this reasoning is correct, at least for smooth-air strafing runs, because it shows a reduction in accuracy when the pilot used the computing sight.

## Lateral-Directional-Stability Requirements

The lateral-stability requirements of references 1 and 2 for satisfactory damping of the classical Dutch roll oscillation are presented in figure 9. Superposed on the criterion is a shaded region of damping period covered in these flight tests. The damping was varied from a well-damped type of oscillation (such as shown in fig. 7) to a neutrally stable type of oscillation. The period of the oscillation was varied from approximately 1.00 second to 4.10 seconds.

These requirements apply only to oscillations which have exponential damping such as shown in figure 4(a). Oscillations such as shown in figure 4(b), which have exponential damping for large amplitudes only and no damping for small amplitudes are not covered by these requirements. The results shown in figure 9, however, include data from both types of oscillations. This was done because a sufficien number of cycles with exponential damping was present to enable the damping to be evaluated in both cases. Data from rudder kicks made with the nose fin oscillating to reduce the damping in yaw were used to obtain points throughout the unsatisfactory region shown in figure 9. The pilot's opinions of these oscillations are possibly influenced by the fact that the rudder kick resulted in a constant-amplitude oscillation, but it is believed that, for the low rates of damping involved in the beginning cycles of the oscillation, the pilot's opinions of the maneuver would be the same even if there was no residual oscillation. The region of very heavy damping was covered also with the use of the nose fin, but the pilot's opinions of this region are not influenced by any residual oscillation.

In the frequency range covered in these tests, the pilots felt that, in general, the present period-damping relationship is adequate for defining the classical Dutch roll oscillatory requirements for fighter airplanes with moderate effective dihedral. The tolerable region shown in figure 9 indicates that the present requirement is slightly on the conservative side with respect to the pilots' opinions.

These results indicate that, if the requirements of references 1 and 2 for satisfactory damping of the classical Dutch roll oscillation are met with an airplane similar to the test airplane, the resulting lateral stability characteristics will be satisfactory to pilots. The test airplane has an effective dihedral angle of approximately 4.5° and a ratio of amplitudes of angle of bank to angle of yaw of approximately 1.2.

The results of some limited stability calculations made to illustrate the method of estimating the reduction in the damping-in-yaw derivative $C_{n_r}$ necessary to change the pilots' opinions of the general flying qualities of this airplane with the nose fin installed from satisfactory to unsatisfactory are shown in figure 10. These calculations were made for one airspeed and altitude by use of the equations of motion of reference 4. The stability derivatives and mass characteristics used in the calculations are given in table III. The damping-in-yaw derivative $C_{n_r}$ was varied from 0 to -0.153.

The damping and period of the oscillatory motion following an abrupt rudder kick made at a Mach number of 0.63 and an altitude of 3580 feet are shown as the flight-test point in figure 10. Using the stability derivatives and mass characteristics given in table III, a value of $C_{n_r}$ of -0.153 resulted in a calculated period and damping approximately equal to the period and damping of the flight-test data. The calculations show that it is necessary to reduce the damping-in-yaw derivative from -0.153 to -0.051 for this speed and altitude to change the pilots' opinions of the flying qualities of the test airplane from the satisfactory region shown in figure 9 to the unsatisfactory region.

### Ability of Pilots to Damp Oscillations

A survey of the flight records has indicated that, in general, the pilots can damp out small-constant-amplitude oscillations of approximately ±1.2° of sideslip up to frequencies of about 0.75 cycle per second. The ability to damp the oscillation varies with pilots and with practice, but, on the average, the oscillations can be stopped in about 1 to 4 seconds. The same oscillation is uncontrollable, however, if the pilot is required to perform other duties at the same time such as those involved in a strafing run. During the strafing runs made in the test airplane the pilots were never able to control completely the oscillation. Even though the pilots could control the oscillation with concentration, during normal-flight maneuvers with the test airplane, the pilots did not usually attempt to damp the oscillation continuously.

## CONCLUSIONS

A preliminary flight investigation of the effect of small-constant-amplitude snaking oscillations on the pilots' opinions of the flying qualities of a fighter airplane with moderate effective dihedral has led to the following conclusions:

1. The pilot's perception of the snaking oscillation is mainly dependent on the transverse acceleration which the oscillation produces.

2. In this airplane, an amplitude of acceleration of ±0.02g was sometimes perceptible to the pilot, but an amplitude of ±0.025g was always perceptible and was considered unsatisfactory for a long flight while an amplitude of ±0.08g was considered very unsatisfactory for any mission this aircraft might perform.

3. In smooth air, small-amplitude oscillations of approximately $\pm 1.2^\circ$ of sideslip reduce the effectiveness of the airplane as a gun platform with either a fixed gun sight or a computing gun sight. In moderately rough air, there is no apparent effect of the snaking oscillation on the effectiveness of the airplane as a gun platform.

4. In general, the present period-damping requirements of the Air Force and Navy are adequate for defining the classical Dutch roll oscillatory requirements for fighter airplanes with moderate effective dihedral.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

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1. Anon.: Specification for Flying Qualities of Piloted Airplanes. NAVAER SR-119B, Bur. Aero., June 1, 1948.

2. Anon.: Flying Qualities of Piloted Airplanes. U. S. Air Force Specification No. 1815-B, June 1, 1948.

3. Weiss, Herbert K.: Analysis of Tracking Errors. Rep. No. 649, Ballistic Res. Lab., Aberdeen Proving Ground, Sept. 11, 1947.

4. Sternfield, Leonard: Some Considerations of the Lateral Stability of High-Speed Aircraft. NACA TN 1282, 1947.

## TABLE I

## BASIC DIMENSIONS OF TEST AIRPLANE

| Item | Wing | Vertical tail |
|---|---|---|
| Area, sq ft | 237 | 22.40 |
| Span, ft | 38.90 | 6.40 |
| Aspect ratio | 6.39 | 2.48 |
| Taper ratio | 0.364 | 0.40 |
| Mean aerodynamic chord, in. | 80.60 | ------- |
| Section | $65_1$-213 | 65-010 |
| Tail length, ft | ------- | 15.3 |

## TABLE II

## PHYSICAL CHARACTERISTICS OF NOSE-FIN INSTALLATION

| | |
|---|---|
| Area, sq ft | 1.64 |
| Span, ft | 1.67 |
| Aspect ratio | 2.64 |
| Taper ratio | 0.53 |
| Section | 65-010 |
| Distance from airplane's center of gravity to flap hinge line, ft | 14.2 |
| Gyro: | |
| Moment of inertia about rotor axis, in.-lb-sec$^2$ | 0.09 |
| Moment of inertia about gimbal axis, in.-lb-sec$^2$ | 0.10 |
| Rotational speed of gyro rotor, rpm | 7800 |
| Flap travel, deg | 10° right, 9° left |

# TABLE III

## STABILITY DERIVATIVES AND MASS CHARACTERISTICS USED IN CALCULATIONS

| | |
|---|---|
| Weight, lb | 11500 |
| Area, sq ft | 237 |
| Span, ft | 38.9 |
| $I_x$, moment of inertia about longitudinal principal axis, slug-ft$^2$ | 11150 |
| $I_z$, moment of inertia about vertical principal axis, slug-ft$^2$ | 24250 |
| $I_{xz}$, product of inertia with respect to the longitudinal and vertical principal axes, slug-ft$^2$ | -229 |
| Velocity, ft/sec | 667 |
| Density, slug/cu ft | 0.002138 |
| $\mu$, airplane relative-density factor | 18.12 |
| $C_L$, lift coefficient | 0.0945 |
| $C_{l_p}$, per radian | -0.538 |
| $C_{l_r}$, per radian | 0.0535 |
| $C_{l_\beta}$, per radian | -0.0612 |
| $C_{n_p}$, per radian | -0.0071 |
| $C_{n_\beta}$, per radian | 0.114 |
| $C_{Y_p}$, per radian | 0 |
| $C_{Y_r}$, per radian | 0 |
| $C_{Y_\beta}$, per radian | -0.456 |
| $\eta$, angle of attack of principal longitudinal axis of airplane; positive when principal axis is above flight path at nose, deg | -1.0 |
| $\gamma$, angle of flight path to horizontal, deg | 0 |

Note:

$C_{l_p} = \dfrac{\partial C_l}{\partial \frac{pb}{2V}}$, $C_{l_r} = \dfrac{\partial C_l}{\partial \frac{rb}{2V}}$, and so forth, where $C_l$ = Rolling-moment coefficien

$C_n$ = Yawing-moment coefficient, $C_Y$ = Side-force coefficient, and
$p$ = Rolling velocity, $r$ = Yawing velocity, $\beta$ = Angle of sideslip

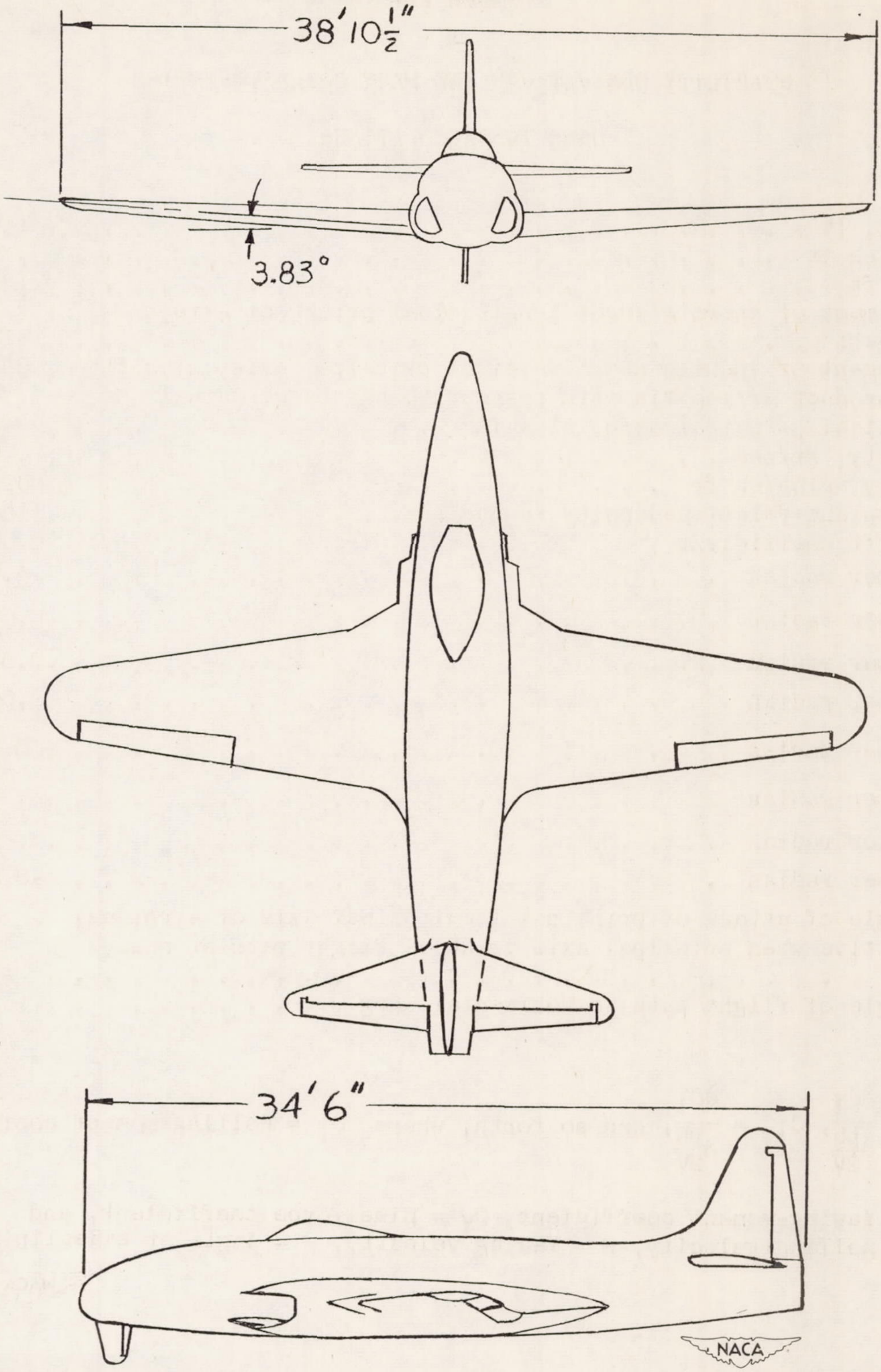


Figure 1.- Three-view drawing of test airplane.

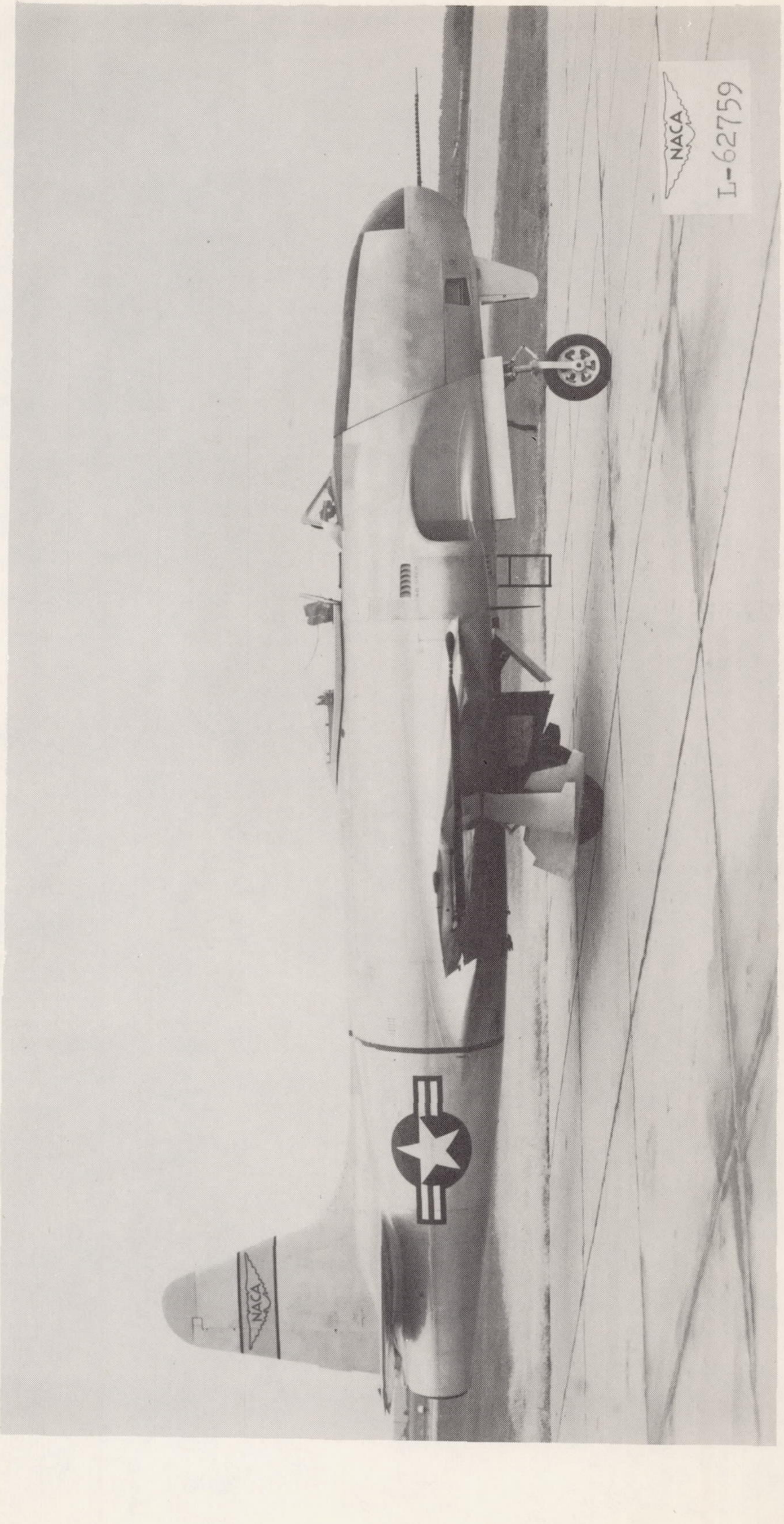
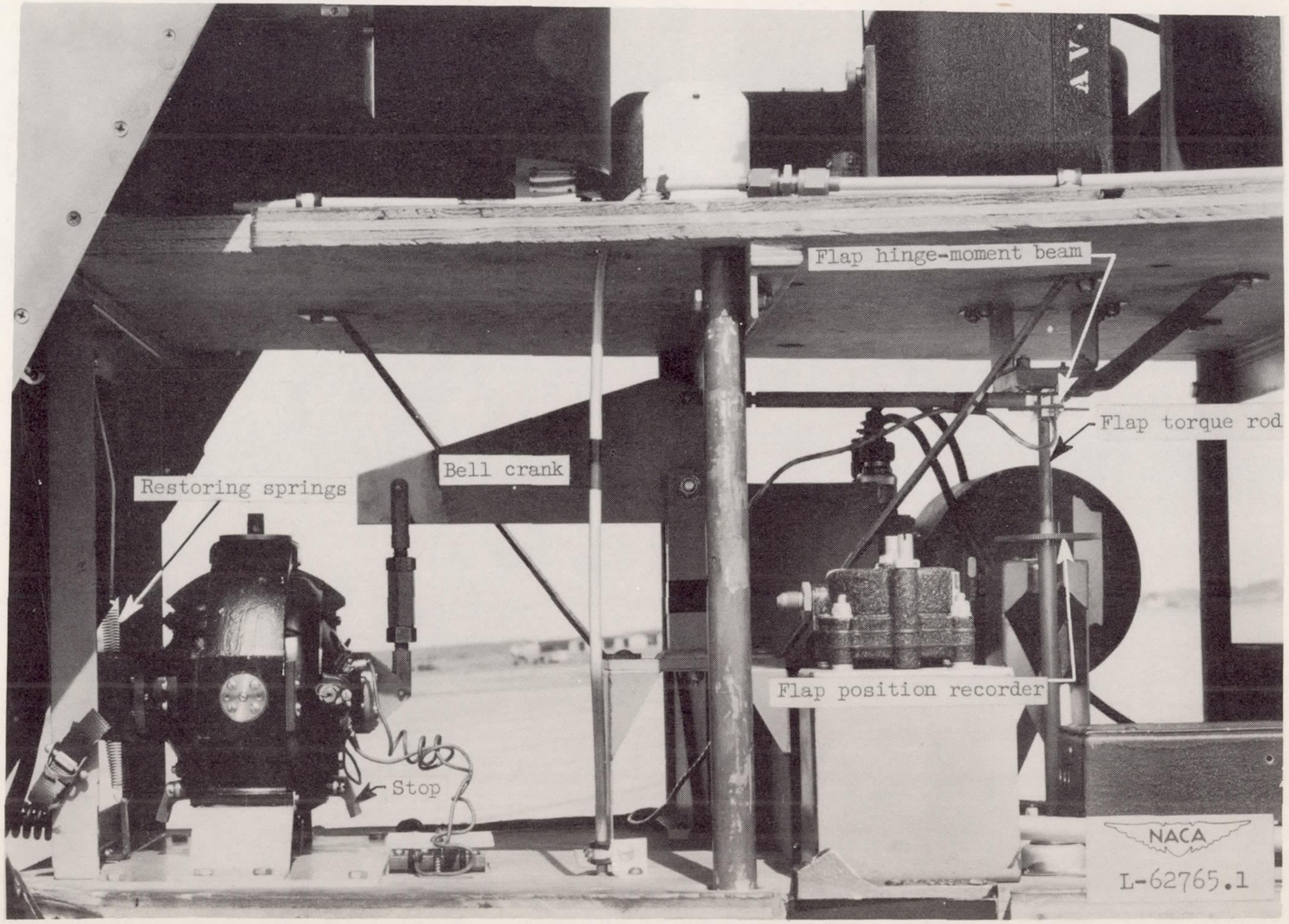


Figure 2.- Side view of test airplane.

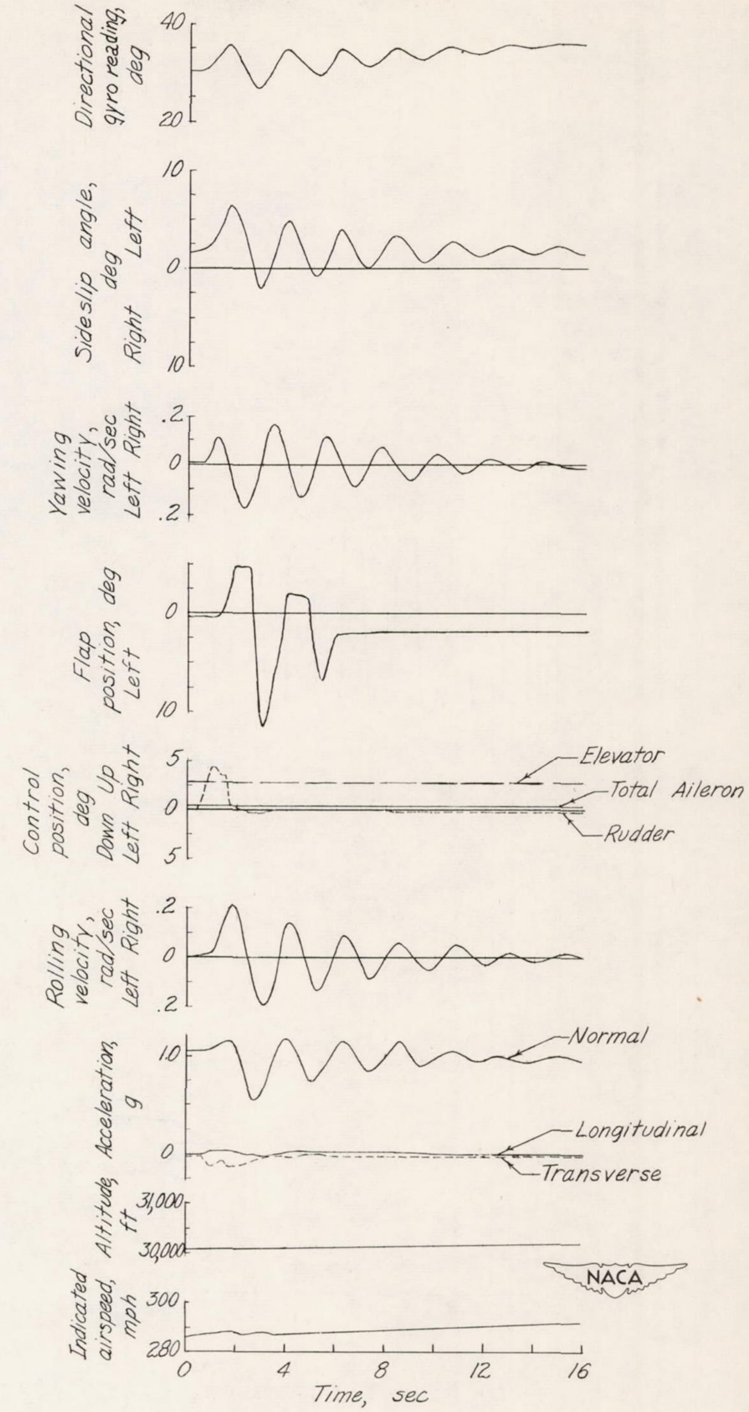
(a) Complete installation.

Figure 3.- Nose-fin installation.



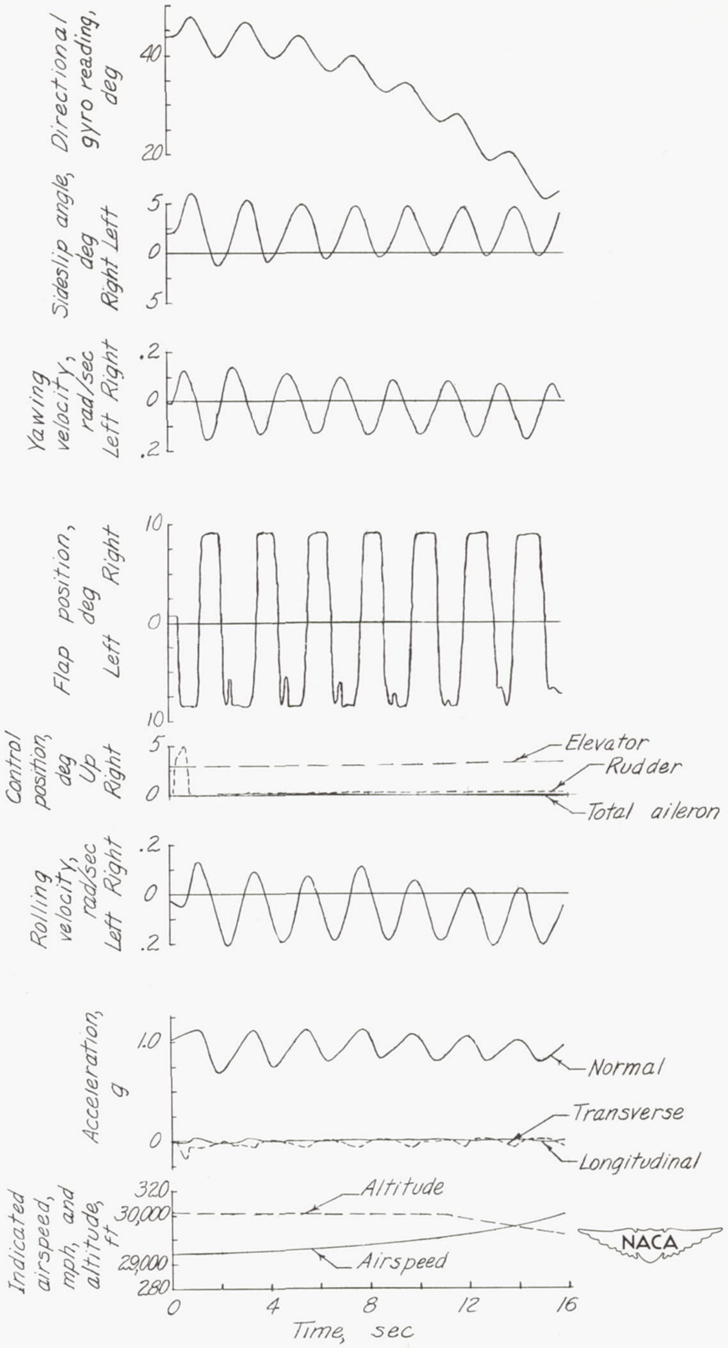
(b) Gyro installation.

Figure 3.- Concluded.



(a) Nose-fin gyro off.

Figure 4.- Time history of a typical lateral oscillation following an abrupt rudder kick in the test airplane.



(b) Nose-fin gyro on.

Figure 4.- Concluded.

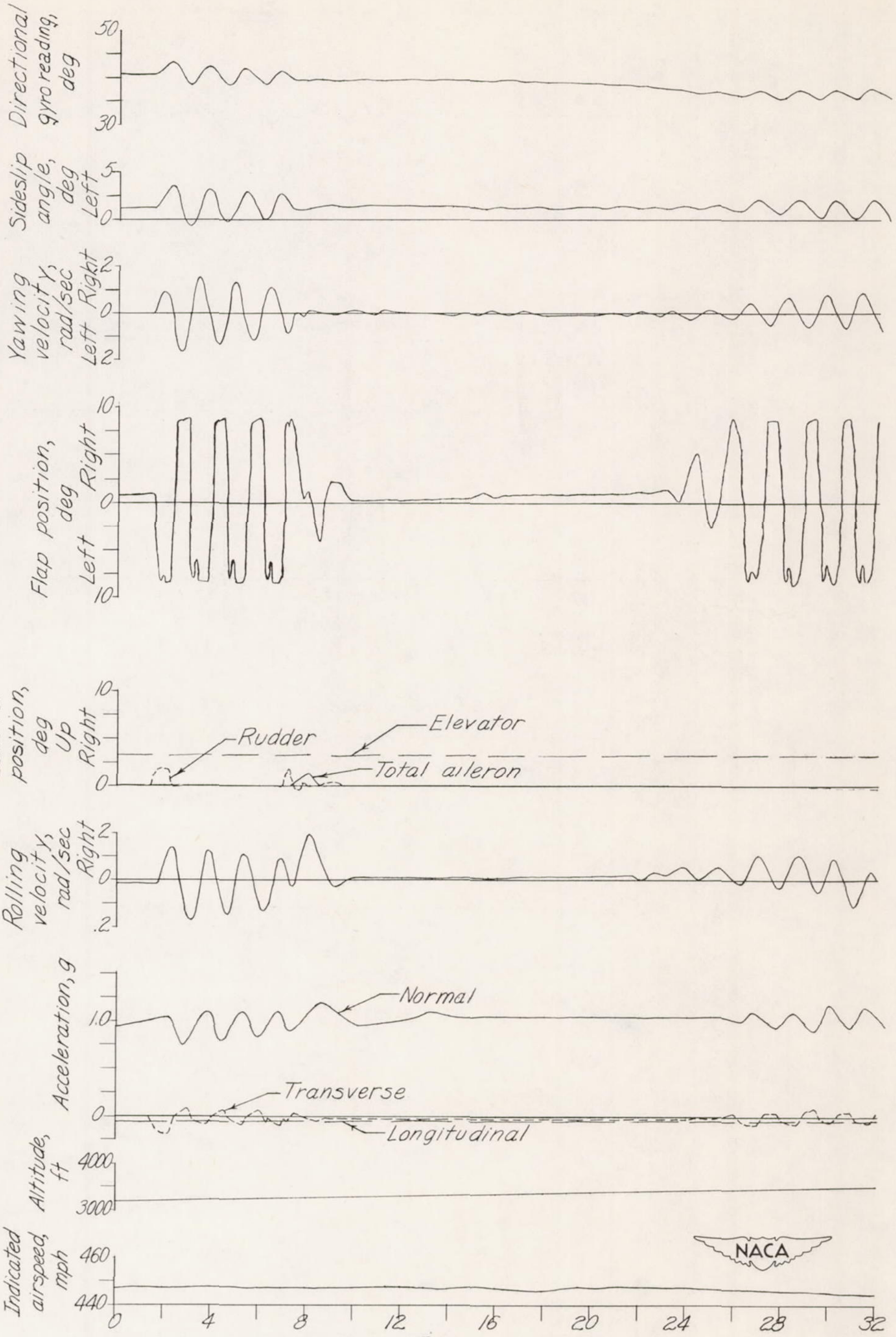


Figure 5.- Time history of a typical lateral oscillation following an abrupt rudder kick and corrective action by the pilot. Gyro on.

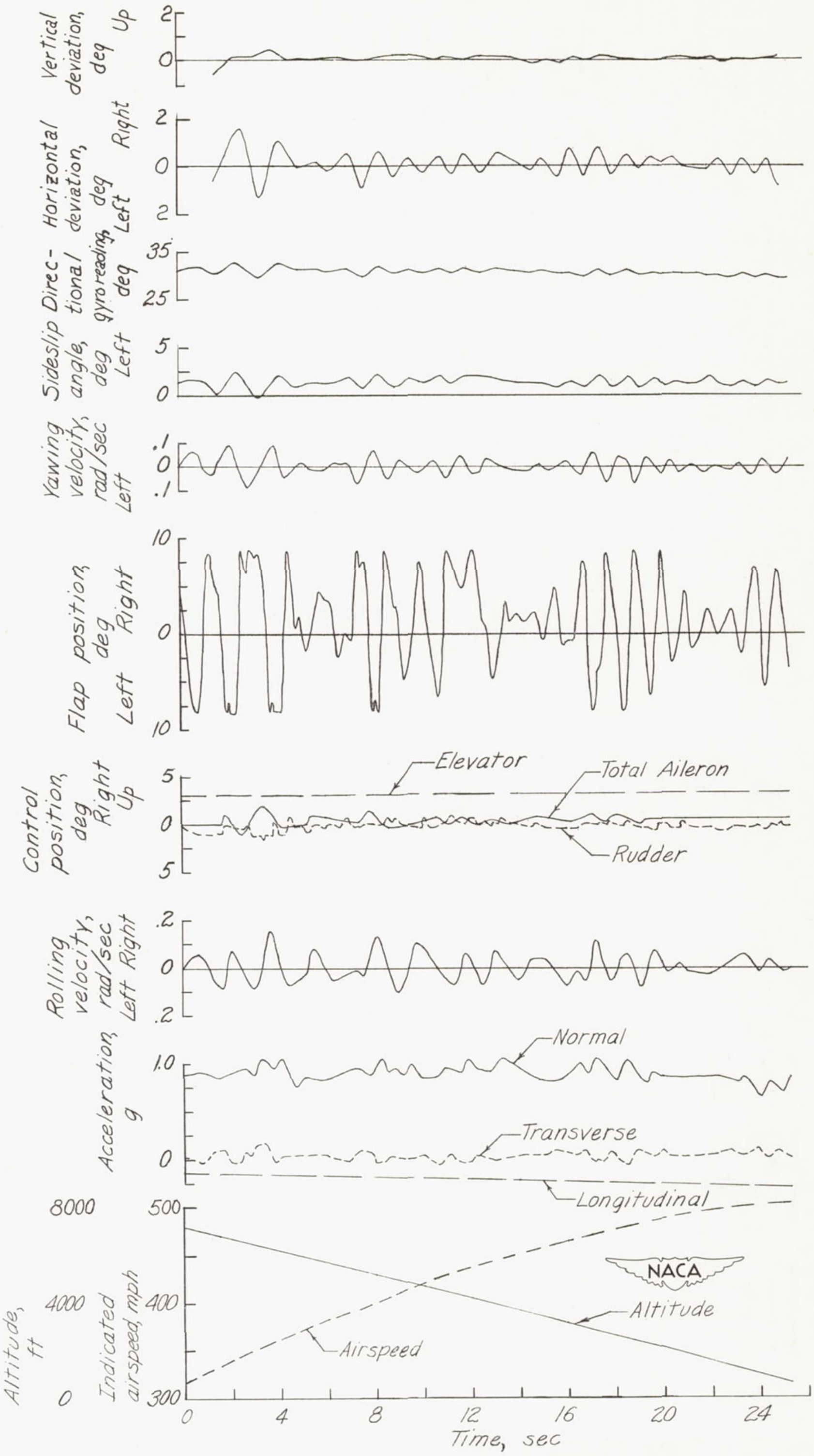


Figure 6.- Time history of a typical strafing run on a fixed ground target with the test airplane.

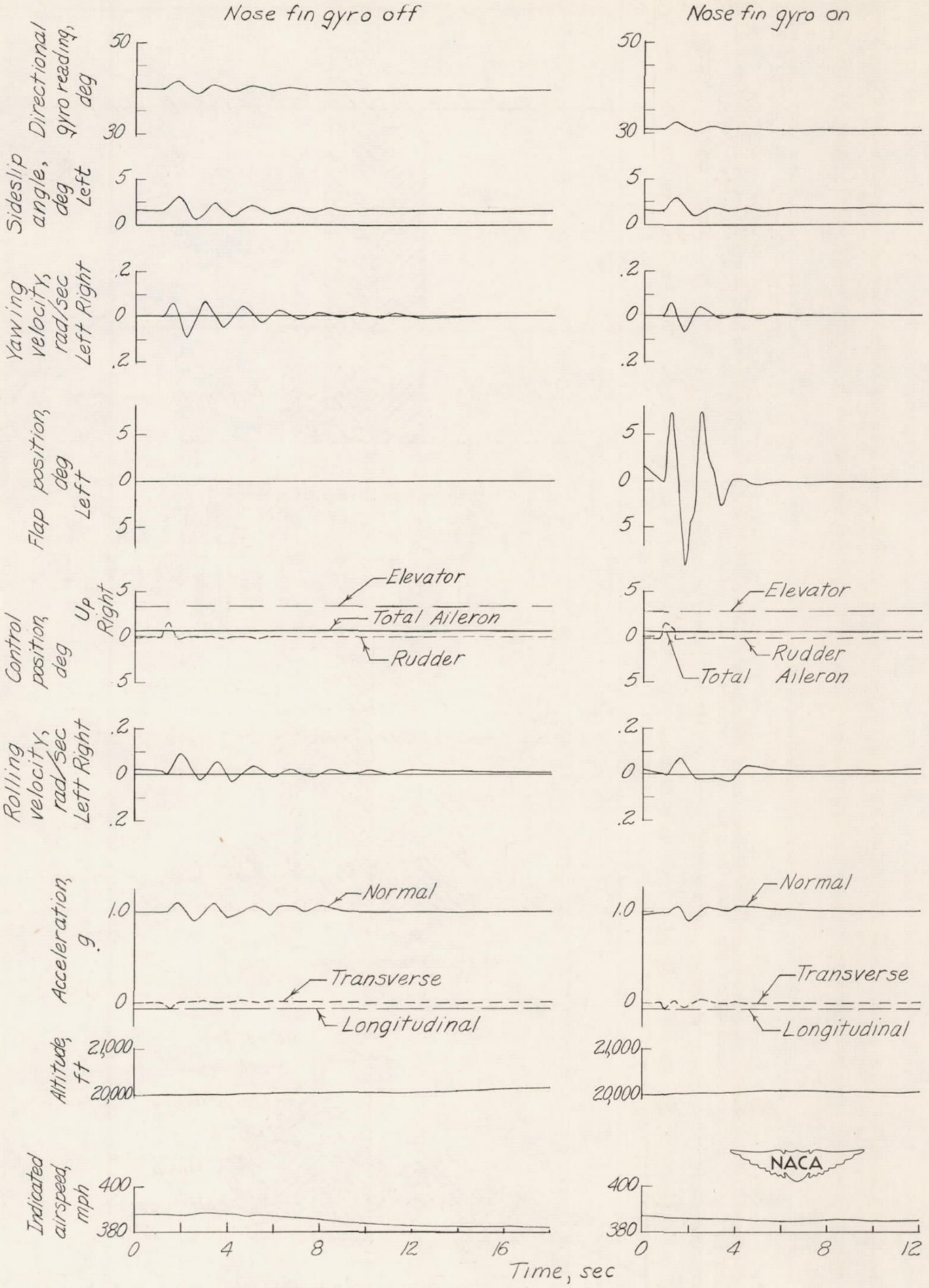
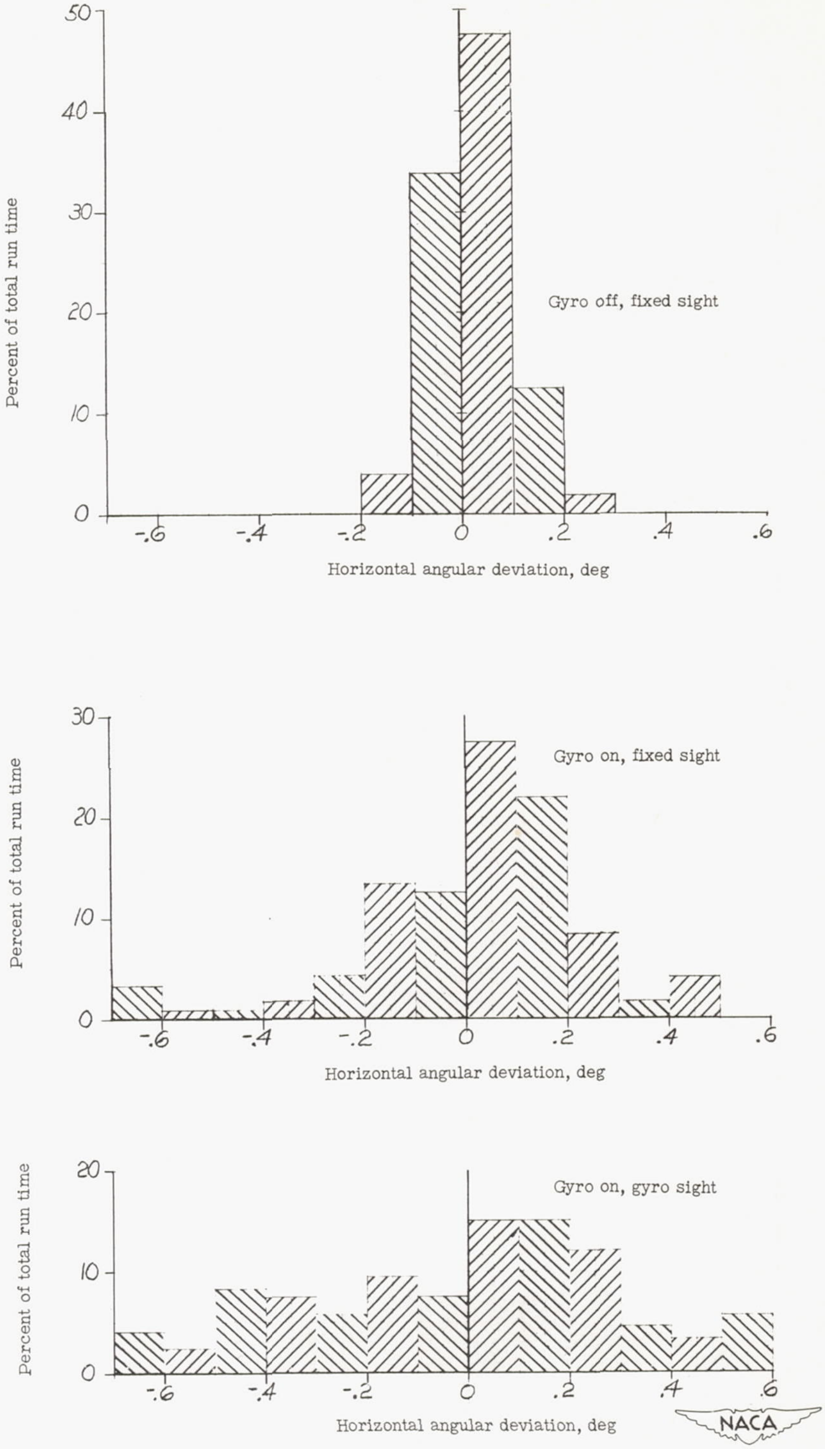
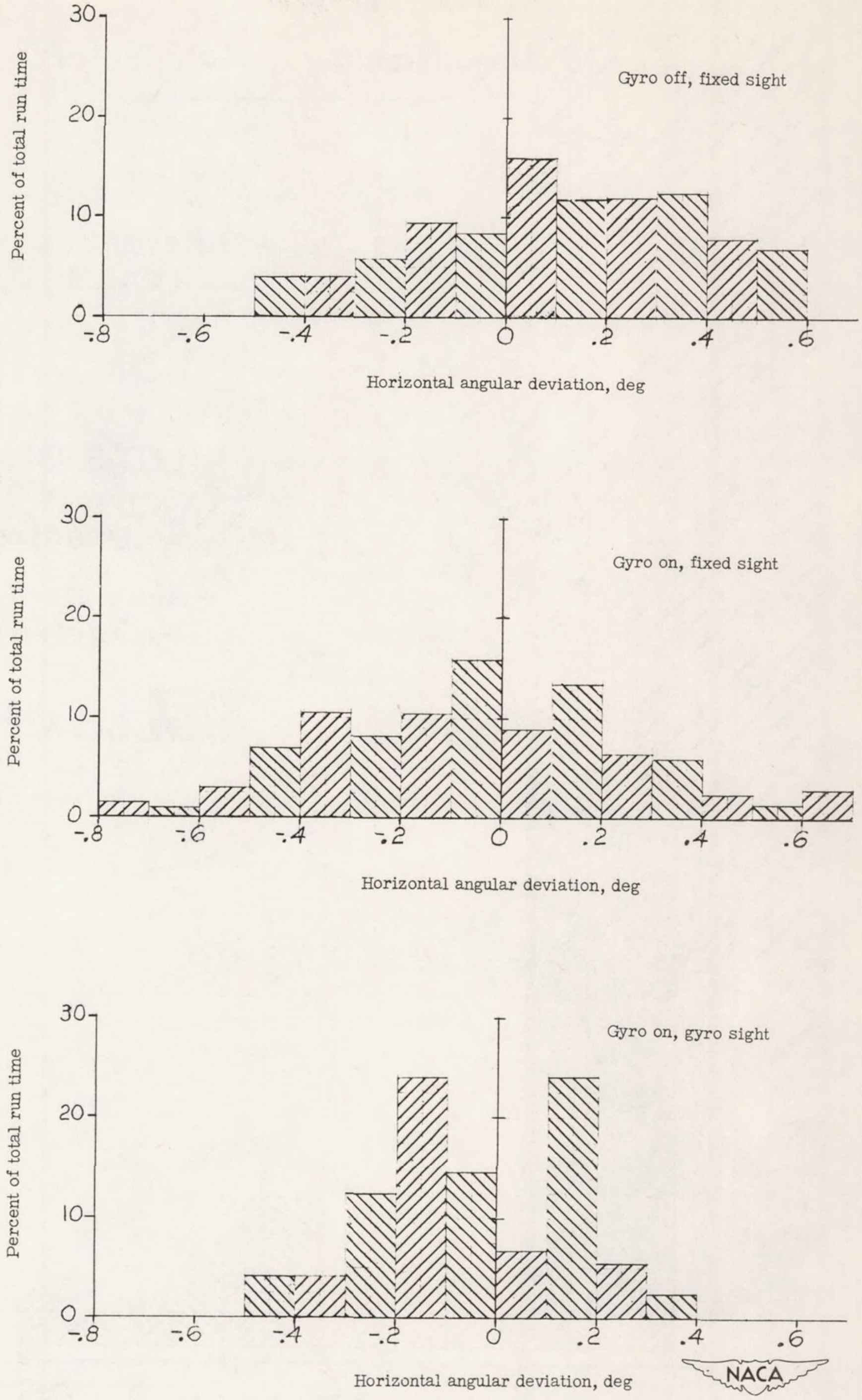


Figure 7.- Time history of a typical lateral oscillation following an abrupt rudder kick with the nose-fin gyro increasing the damping in yaw.



(a) Normal-acceleration variation ±0.12g.

Figure 8.- Typical distribution of gun sighting errors during a strafing run on a fixed ground target in the test airplane.



(b) Normal-acceleration variation ±0.40g.

Figure 8.- Concluded.

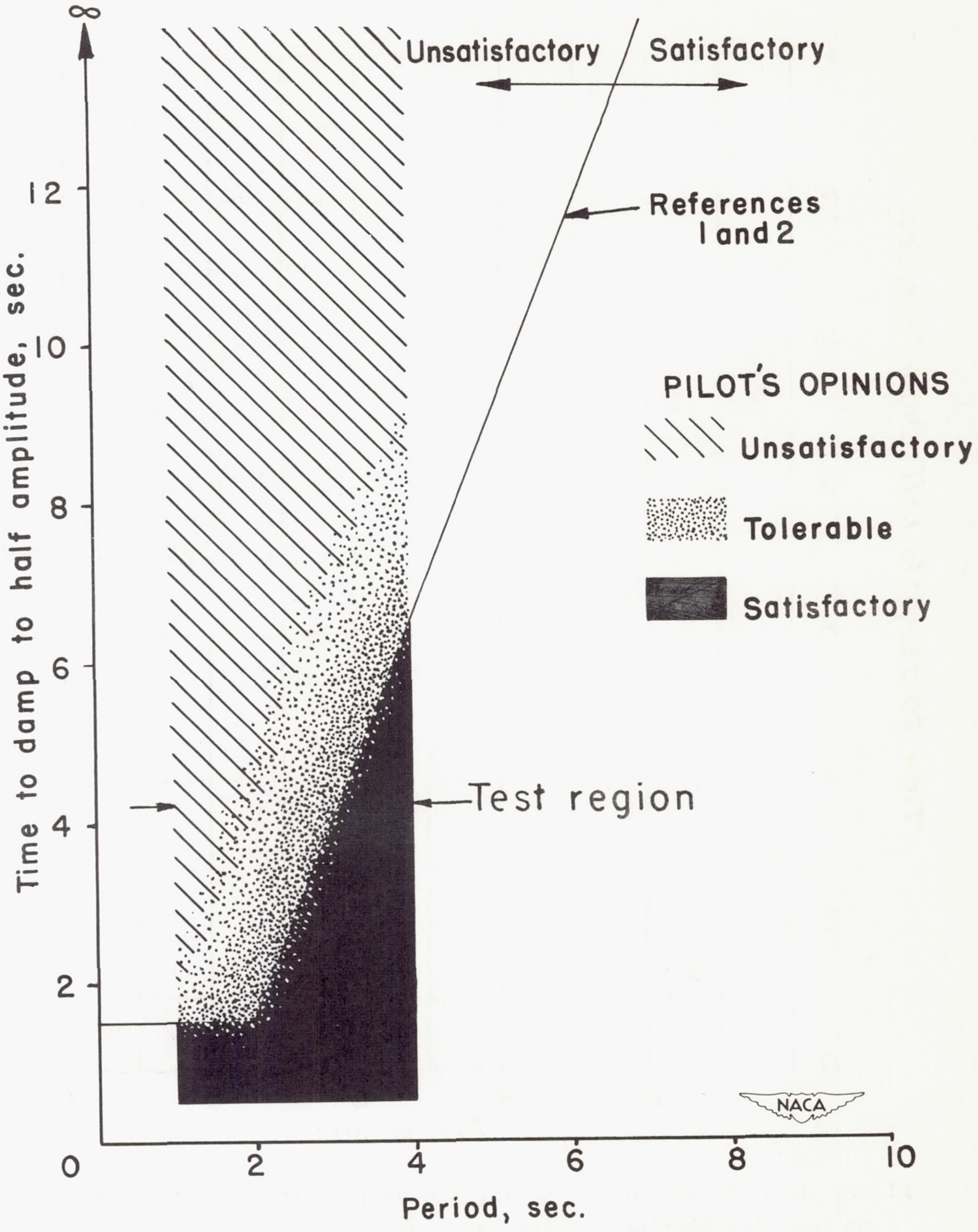


Figure 9.- Comparison of pilots' opinions of the over-all lateral characteristics of the test airplane with the period-damping requirements of references 1 and 2.

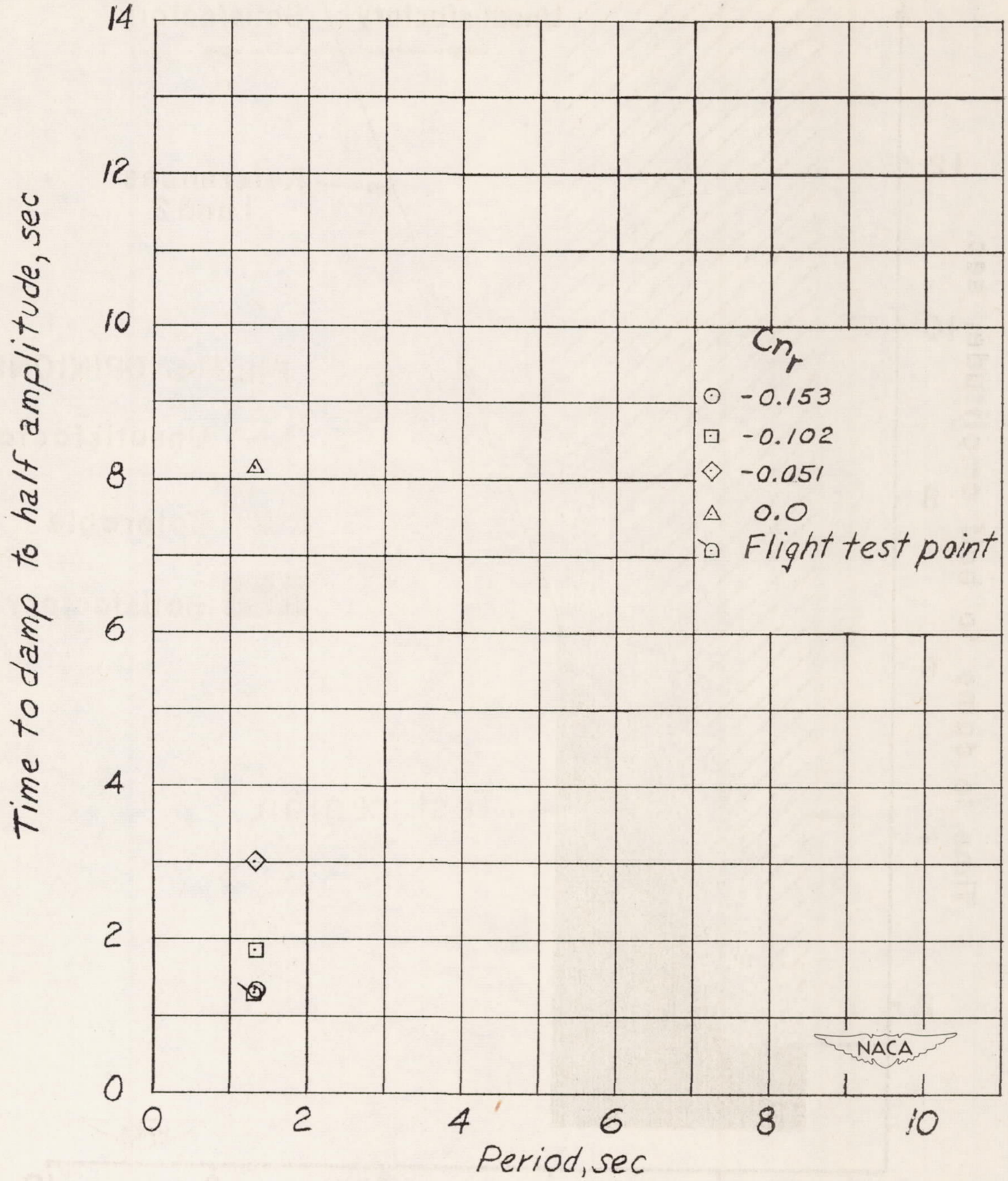


Figure 10.- The effect of varying the damping-in-yaw derivative $C_{n_r}$ of the test airplane on the calculated period and damping of the lateral directional oscillation.