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FLYING QUALITIES AND STALLING CHARACTERISTICS OF NORTH AMERICAN XP-51 AIRPLANE

(A.A.F. No. 41-38)

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and Howard W. Garris

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MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

FLYING QUALITIES AND STALLING CHARACTERISTICS OF NORTH AMERICAN XP-51 AIRPLANE

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INTRODUCTION

At the request of the Army Air Forces, a flight investigation of the flying qualities and stalling characteristics of a North American XP-51 airplane was conducted by the NACA at Langley Field, Va. The results of these tests are presented in the following report. This is the first airplane to be tested at the Laboratory fitted with a wing having a low-drag airfoil section.

The flying-qualities tests, which were made subsequent to a flight investigation of the wing drag, were begun about March 1, 1942 and were completed about May 15, 1942; a total of 22 flights were made requiring approximately 21 hours of flying time.

In addition to this report, a report has been written covering the results of tests of a set of modified ailerons (reference 1).

DESCRIPTION OF THE XP-51 AIRPLANE

The North American XP-51 airplane is a single-engine, low-wing, pursuit-type monoplane (figs. 1, 2, 3, and 4). Descriptive data and dimensions are listed as follows:

Airplane	North American XP-51 (A.A.F. No. 41-38)
Over-all length	32 ft $2\frac{5}{8}$ in.
Height	11 ft 9 in.
Engine	Allison V-1710-39
Rating:	
Take-off	1150 hp at 2800 rpm and 46.8 in. Hg at sea level
Military	1150 hp at 3000 rpm and 45.9 in. Hg at 9600 feet
Normal	1000 hp at 2600 rpm and 39.5 in. Hg at 9000 feet
Propeller	Curtiss constant-speed
Diameter	10 ft 6 in.
Number of blades	3
Wing	
Area	235.75 sq ft
Span	37.03 ft
Root chord (center of airplane)	103.99 in.
Tip chord, at station 215 in.	60 in.
Taper ratio	2.16 to 1
Aspect ratio	5.815
Incidence (at root)	1°
Dihedral (at 25-percent line)	5° (mean of upper and lower surfaces)
Sweepback (leading edge)	3° 35' 32"
Washout at tip	1°
Mean aerodynamic chord	79.6 in.
Leading-edge M.A.C. location relative to leading-edge wing (root chord)	8.0 in. above 6.1 in. aft
Airfoil section	low drag; minimum pressure at 0.4c (fig. 5)
Airfoil thickness ratio	0.165 at center line to 0.115 at tip
Wing flaps	
Type	plain
Total area	32.22 sq ft
Span (each)	$11\frac{1}{4}$ in.
Chord:	
Inboard	23 in.
Outboard	17 in.

Ailerons
- Area (each, including 0.73 sq ft tab) . . . . . 6.7 sq ft
- Length . . . . . 6 ft $11\frac{3}{8}$ in.
- Tabs:
  - Left aileron tab, combination booster and trim . . . . . 4 in. × $26\frac{1}{4}$ in.
  - Right aileron tab, booster only . . . . 4 in. × $26\frac{1}{4}$ in.

Stabilizer (fixed)(see fig. 5)
- Area (including section through fuselage) . . 28.05 sq ft
- Normal setting (relative to longitudinal axis) . . . . . 2°

Elevator (see fig. 5)
- Area (including 1.0 sq ft tab) . . . . . 13.05 sq ft
- Span . . . . . 13 ft 2 in.
- Maximum chord behind hinge line . . . . . 17 in.
- Trim tab size (each) . . . . . $1\frac{3}{8}$ in. × $31\frac{1}{2}$ in.
- Balance area (shielded horn balances) . . . . 0.24 sq ft

Vertical tail, total area (see fig. 5). . . . . 23.22 sq ft
- Fin area . . . . . 9.51 sq ft
- Normal setting . . . . . 2° left

Rudder (see fig. 5)
- Area (including 0.81 sq ft tab) . . . . . 10.41 sq ft
- Vertical span . . . . . $71\frac{1}{4}$ in.
- Trim tab size . . . . . $5\frac{1}{4}$ in. × 22 in.
- Maximum chord behind hinge line . . . . . 22 in.

The deflections of the various controls and control surfaces as measured on the ground with no load were as follows:

Control surface	Surface deflection	Control movement or trim tab indicator setting
Elevator	24.5° up - 25° down	17 in. total at top of stick
Rudder	30.5° left - 32.5° right	7 in. total at pedal
Ailerons	±10° (see fig. 6)	18 in. total at top of stick
Wing flap	49.5° down	
Elevator trim tab	10° nose heavy - 22° tail heavy	10° nose heavy - 22° tail heavy
Rudder trim tab	8.0° nose right - 11.5° nose left	8° nose right to 14.5° nose left
Aileron trim tab	11.5° right - 9° left	10° right - 10° left
Aileron booster tab linkage:		
Left wing	0.45	
Right wing	0.50	

	Normal	Maximum
Fuel capacity, gal	107	170
Oil capacity, gal	7.5	12

Horizontal distance from elevator hinge line to leading-edge wing at center line . . 19 ft $7\frac{3}{4}$ in.

Horizontal distance from rudder hinge line to leading-edge wing at center line . . 21 ft $5\frac{3}{4}$ in.

Maximum fuselage cross-sectional area, approx. . 13.4 sq ft

Wheel base . . . . . 142 in.

Control friction was measured on the ground with no load on the surfaces, and values are given in table I.

The aileron trim tab was on the left aileron only. This left aileron trim tab and the tab on the right aileron both act as balancing tabs to relieve aileron-control forces.

INSTRUMENT INSTALLATION

Standard NACA recording instruments were used in the investigation. The instruments used and the items recorded are listed in the following table:

Item	NACA instrument
Airspeed	Airspeed recorder
Control-surface position	Control-position recorders
Control forces	Rudder-force recorder and two-component stick-force recorder
Angular velocities about three airplane axes	Recording turnmeters
Acceleration along airplane axes	Recording three-component accelerometer
Angle of sideslip	Recording yaw vane
Angle of bank or pitch	Recording inclinometer
Time	Timer

All of the records were synchronized by means of the timer.

The yaw vane was mounted on a boom extending about a chord length ahead of the right wing tip.

An aileron control-position recorder was used for each aileron and was connected to the control cables in the immediate vicinity of the surfaces in order to minimize the effects of the elasticity of the system under load.

The airspeed recorder was connected to a shielded total head and a free-swiveling static head mounted on a boom extending a chord length ahead of the left wing tip.

CALIBRATION OF PILOT'S AIRSPEED METER

The installation of the service airspeed indicator in the XP-51 airplane consisted of a pitot-static head located 18.4 inches below and 34.8 inches aft of the leading edge of the right wing and in line with the inboard end of the aileron (fig. 4).

This service airspeed head and the NACA airspeed recorder installation were calibrated by flying in formation with another airplane, the airspeed recorder of which had been calibrated by means of a trailing static head. Variation of the indicated values of the XP-51 service airspeed head with correct indicated airspeed is shown in figure 7.

"Correct indicated airspeeds" as used in the present report is defined by the relation

$$V_i = 45.08 \sqrt{q_{c_{in.\ H_2O}}}$$

where q_c, the impact pressure, is corrected for installation errors.

DESCRIPTION OF TESTS

Tests were made with the airplane center-of-gravity location ranging from 24.3 percent to 29.3 percent of the mean aerodynamic chord, except for several landing tests made with the center of gravity farther forward. The gross weight varied from about 7200 to 7800 pounds. A considerable

forward movement of the center of gravity occurred as fuel was consumed (about 1 percent of the mean aerodynamic chord for each 40 gallons). Corrections have been made for this effect.

The flight conditions in which tests were made are defined in the following table:

Flight condition	Flaps	Landing gear	Radiator scoop position	Manifold pressure, in. Hg	Engine rpm
Cruising	up	up	Neutral (partially open)	29.5	2230
Combat	20°	--do.--	Neutral (partially open)	39.5	2600
Gliding	up	--do.--	Scoop closed, deflector down	Throttle closed	----
Climbing	up	--do.--	Neutral (partially open)	39.5	2600
Take-off	up	down	Neutral (partially open)	46.8	2800
Take-off	20°	--do.--	Neutral (partially open)	46.8	2800
Wave-off	50°	--do.--	Neutral (partially open)	46.8	2800
Landing	50°	--do.--	Neutral (partially open)	Throttle closed	----
Landing approach	20°	--do.--	Neutral (partially open)	29.8	2600

The various configurations of the radiator scoop used in the tests are shown in figure 8. The deflector, shown in the deflected position in figure 8, was actually deflected only in the gliding condition of flight. The cockpit

windows were closed in all tests except when the effect of opening them was investigated specifically.

RESULTS AND DISCUSSION

In the presentation and analysis of the results of the tests, the standards used for comparison were the flying-quality requirements listed in reference 2.

I. Longitudinal Stability and Control

I-A. Characteristics of uncontrolled longitudinal motion

The characteristics of the uncontrolled longitudinal motion were investigated at various airspeeds throughout the respective airspeed ranges for the cruising, gliding, and landing conditions. The tests for the short-period oscillations were made by trimming the airplane at each speed, then taking continuous records as the elevator control was abruptly deflected and released.

The results indicate that the short-period oscillations of the airplane are well damped for all conditions, including the critical high-speed condition, and fulfill the requirement that the oscillation shall disappear within one cycle. The movement of the elevator also appears well damped although for certain conditions about two cycles are required to effect complete damping of the motion. This effect is generally obscured, however, by the effect of friction (see table I) which, while only of the order of 1.5 pounds of

stick force, nevertheless resulted in the elevator coming to rest at a position other than that required for trim. Typical time histories of short-period longitudinal oscillations in the cruising condition at 119 and 248 miles per hour with the center of gravity at 25.1 percent of the mean aerodynamic chord are shown in figure 9.

I-E. Characteristics of elevator control in steady flight

The characteristics of the elevator control in steady flight were determined by recording the elevator position and force required for trim at various speeds in the following conditions:

Flight condition	Center-of-gravity position, percent M.A.C.	Scoop position	Flaps	Manifold pressure, in. Hg	Rpm	Figure
Cruising	24.5	Neutral	up	29.5	2280	10(a)
Cruising	29.2	---do.--	up	29.5	2280	10(a)
Gliding	24.5	Closed, deflector down	up	Throttle closed	----	10(b)
Gliding	29.5	Closed, deflector down	up	Throttle closed	----	10(b)
Climb	25.6	Neutral	up	39.5	2600	11
Climb	29.7	---do.--	up	39.5	2600	11
Take-off	25.3	---do.--	up	46.8	2800	12(a)
Take-off	24.9	---do.--	20° down	46.8	2800	12(a)
Wave-off	24.6	---do.--	50° down	46.8	2800	12(c)
Landing	24.3	---do.--	50° down	Throttle closed	----	13(a)
Landing	28.5	---do.--	50° down	Throttle closed	----	13(a)
Landing approach	24.6	---do.--	20° down	20.0	2600	13(b)

The results of these tests, which are presented in figures 10 through 13 (see preceding table), indicate the following conclusions:

1. In all conditions of flight and at each center-of-gravity position tested, stick-fixed static stability was indicated by the negative slopes of the curves of elevator angle against airspeed. However, in the power-on conditions, trim at low speeds was accompanied by more sideslip than at high speeds which, as can be seen by reference to the sideslip results in figures 31 through 38, made it necessary to use more up-elevator deflection at low speeds. The magnitude of the effect was comparable with that of some other pursuit-type airplanes. For all flight conditions, therefore, the requirements of reference 2 were met although the stick movement in some conditions was very small. In the cruising and climbing conditions, for the rearward center-of-gravity positions, for example, the top of the stick was required to move less than 1 inch from 300 miles per hour to the stall to maintain trim.

2. In all conditions of flight tested, the variation of stick force with airspeed was small but stable throughout the respective speed ranges. Despite the small magnitude of the force gradients, the force characteristics were considered adequate by the pilots.

The center-of-gravity positions at which neutral longitudinal stability would occur for stick-fixed and stick-free conditions are listed in table II. These neutral stability points were determined by plotting $d\delta_e/dC_L$ and dC_h/dC_L as a function of center-of-gravity position,

where

δ_e elevator deflection

C_h elevator hinge moment

C_L airplane lift coefficient

It will be noted that freeing the controls had but little effect on the longitudinal stability.

3. As measured on the ground, the friction in the elevator control system was about $1\frac{1}{2}$ pounds. (See table I.) This friction was sufficient to prevent the control from returning immediately to its trim position following an abrupt deflection (fig. 9). Due to vibration of the airplane, the stick would creep toward its trim position as illustrated in the time history shown in figure 9; the effect of friction, therefore, did not influence the data in the force curves of figures 10 through 13, since sufficient time was allowed for the control to reach its steady position in each case.

4. The elevator required for trim was well within the available elevator travel throughout the speed range in all conditions of flight tested.

I-C. Characteristics of the elevator control in accelerated flight

The characteristics of the elevator control in accelerated flight were determined from measurements taken in rapid 180° turns. Time histories of representative turns are shown in figures 14 through 20. The results of these tests may be summarized as follows:

1. Although the load factor of 8g was never actually attained in any of the tests, it was determined by extrapolation of available data that the elevator control was sufficiently powerful to develop either the allowable load factor or the maximum lift coefficient at all speeds. In one of the forward center-of-gravity positions tested, 25.5 percent of the mean aerodynamic chord, the maximum lift coefficient was attained in a 180° turn using less than half the available stick travel (fig. 21(a)).

2. As shown by the time histories, figures 14 through 20, and the summary curve shown in figure 21(a), the variation of elevator angle with normal acceleration in the steady 180° turns was stable. By extrapolation,

it is seen that, with the center of gravity at about 32.3 percent of the mean aerodynamic chord, the stick-fixed turning-flight stability would be neutral.

3. The stick movement required to change the angle of attack from a lift coefficient of 0.2 to the maximum lift coefficient was 2.4 inches with a center-of-gravity position of 25.5 percent of the mean aerodynamic chord. With the center of gravity at 28.9 percent of the mean aerodynamic chord, the corresponding stick travel was only 1.2 inches (fig. 21(a)). This characteristic resulted in the airplane being somewhat sensitive to small movements of the stick, as illustrated in the time histories of 180° turns in figures 14 through 20 where the normal acceleration fluctuates due to almost imperceptible elevator movements. However, with the aid of the satisfactory stick-force gradient discussed later, these stick movements were kept small enough so that the resulting motions were not considered objectionable.

4. As measured in steady 180° turns, the normal acceleration varied linearly with stick force. This variation is shown in figure 21(b) for two center-of-gravity locations in both combat and cruising conditions of flight. This linear variation is desirable as an aid to the pilot in obtaining and holding a given acceleration.

5. In figure 21(b) the variation of stick force with acceleration is shown to be 8.3 pounds per "g" for the forward center-of-gravity position (25.5 percent of the mean aerodynamic chord) for both cruising and combat conditions. This value is nearly equal to the recommended upper limit of force gradient of 8 pounds per g. (On the basis of tests made subsequent to the writing of reference 2, the value of 6 pounds per g quoted there as an upper limit for satisfactory stick-force gradient has been revised to 8 pounds per g.) With the center of gravity at 28.9 percent of the mean aerodynamic chord, the stick-force variation with normal acceleration was about 4.4 pounds per g.

It appears from extrapolation of the data (fig. 21(b)) that no force gradient at all would be experienced in steady turns in the cruising condition with the center of gravity at 32.7 percent of the mean aerodynamic chord. This value of center-of-gravity position at which the force gradient in turns becomes zero agrees reasonably well with the value of 32.3 percent of the mean aerodynamic chord obtained for zero stick position gradient in turns indicating the variation of elevator floating angle with angle of attack to be small.

The above results correspond to an altitude of about 7000 feet. At higher altitudes, lower forces will be experienced for a given acceleration due to the decrease in required elevator deflection resulting from the increased radius of turn.

At a center-of-gravity position of 28.9 percent of the mean aerodynamic chord, the data of figure 21(b) indicate a force of 30 pounds will be necessary to obtain the allowable load factor of 3g in the cruising condition. At center-of-gravity positions farther aft, values lower than 30 pounds, the minimum value specified in reference 2, will be required. These results appear to establish 28.9 percent of the mean aerodynamic chord as the rearmost position and 25.5 percent of the mean aerodynamic chord as the most forward position at which the requirements of reference 2 for stick forces in turns will be satisfied.

Values for the combat condition are comparable with those for the cruising condition.

I-D. Characteristics of the elevator control in landing

1. The results of tests to determine the elevator deflection required for landing are shown in figure 22, where the elevator deflection at the time of contact is plotted against center-of-gravity position for a group of three-point landings. It is seen that the elevator

power is sufficient to execute three-point landings with the center of gravity as far forward as 21.5 percent of the mean aerodynamic chord. No perceptible difference in elevator requirements is evident between flap deflections of 50° and 35°.

The elevator deflections noted are about 8° greater than those required to stall at altitude in the same condition.

2. The stick forces required to make three-point landings were well below the upper limit of 35 pounds recommended in reference 2. A typical landing history (fig. 23) shows a maximum stick force before contact of 20 pounds. This value, which corresponds to a trim-tab setting of 10° tail heavy, could be reduced somewhat by further trim-tab deflection.

I-E. Characteristics of the elevator control in take-off

The elevators were adequate to raise the tail or to adjust the attitude angle as desired during take-off after approximately one-half take-off speed was reached. This conclusion is based on pilot's observations. Figure 24, a time history of a typical take-off in which the tail was raised quickly, is presented as a matter of interest to indicate the control movements required during the take-off.

I-F. Trim changes due to power and flaps

1. Trim changes due to changes in flight condition or airplane configuration are shown in table III. These changes in elevator angle and forces are given for 120 miles per hour only. All values in table III are for approximately the same center-of-gravity position. It may be seen from the static stability curves (figs. 10 through 13) that these changes will differ for other speeds. In most cases, however, the changes due to change in flight condition are small, coming well within the upper limits recommended in reference 2.

A change in longitudinal trim, amounting to 0.8° of up-elevator deflection, resulted from opening the side windows of the cockpit enclosure.

The effect of varying the radiator scoop position was also investigated; as shown in table III, the resulting trim changes were small.

I-G. Characteristics of longitudinal trimming device

1. To determine the power of the elevator trim tabs, measurements were made of the elevator forces required for trim with several different trim-tab settings and at several speeds. The results are shown in figure 25 where the change in stick force per degree trim-tab deflection is plotted against airspeed for four flight conditions. Combining these data with the

static stability data of figures 10 through 13, it is evident that the power of the trim tabs is ample to satisfy the requirements of reference 2 with the center of gravity as far forward as 24.5 percent of the mean aerodynamic chord, the most forward position at which tests were made. For example, in the landing condition it is possible to trim the airplane between 120 percent and 140 percent of the minimum speed and in the cruising condition the airplane could be trimmed at all speeds above 120 percent of the minimum speed.

2. Unless changed manually, the trimming device would retain a given setting indefinitely.

II. Lateral Stability and Control

II-A. Characteristics of uncontrolled lateral and directional motion

1. The characteristics of control-free lateral oscillations were determined by trimming the airplane for straight laterally level flight at each speed and flight condition and then quickly deflecting the rudder and releasing all controls. Records were taken of the variation of rolling, yawing, and pitching velocities, sideslip angle, control forces, and control positions in the resulting oscillations. These measurements were taken at several airspeeds between 91 and 243 miles per hour.

The variation of the period of the lateral oscillation and of the number of cycles to damp to one-half amplitude for the cruising, gliding, and landing conditions are shown in figure 26. Figure 26 shows that the lateral oscillation is damped to one-half amplitude in less than one cycle for all conditions tested, meeting by a considerable margin the requirements of reference 2 that the oscillation damp to one-half amplitude in less than two cycles.

2. No records were obtained of the oscillations of the ailerons following an abrupt deflection and release of the control, but pilot's observations indicate that the motions are satisfactorily damped.

3. Due to friction in the rudder-control system, the rudder failed to meet the requirement that it return to the trim position following an oscillation of the control induced by abrupt deflection. This characteristic is illustrated by figure 27 showing typical time histories of the motions following abrupt rudder kicks. When the rudder was released following the kick it came to rest, under the influence of sideslip, at a different position than trim and was held there by friction. This effect was more pronounced at low speeds where the aerodynamic forces tending to return the rudder to its trim position were less than at high speeds, and as a

result the airplane failed to return to straight flight following the oscillation.

II-B. Aileron-control characteristics

The aileron-control characteristics were obtained by recording the airspeed, rolling velocity, aileron deflection, and stick forces as the ailerons were deflected abruptly and held, with the rudder held fixed. The results for the cruising condition are included with the results for the landing and combat conditions in figures 28 through 30 and in table IV.

Figures 28 and 29 show the variation of aileron effectiveness as defined by the parameter $pb/2V$, and of aileron stick force with control deflection at various airspeeds. Figure 30 is a summary curve showing the maximum values of $pb/2V$ obtainable at each speed and the corresponding stick forces. Where the stick forces exceed 30 pounds, the maximum value recommended in reference 2, the values of $pb/2V$ for a 30-pound stick force are also shown. The relative effectiveness of the aileron controls in each flight condition is compared in table IV.

The results of these tests may be summarized as follows:

1. Throughout the speed range, the maximum rolling velocity obtained by abruptly deflecting the ailerons varied smoothly with the aileron deflection and was

approximately proportional to the aileron deflection. This is shown by the linear variation of aileron effectiveness on figures 28 and 29.

2. The rolling acceleration following an abrupt aileron deflection was always in the correct direction and no lag in the development of the rolling moment was evident.

3. For evaluating the aileron effectiveness the helix angle $pb/2V$, in which p is rolling velocity in radians per second, b is the span in feet, and V is the true airspeed in feet per second, has been used as the criterion (reference 3).

Except in low-speed rolls to the left in the combat condition, the ailerons failed to meet the requirement that $pb/2V$ of 0.07 be obtainable. In this one exception the value of 0.07 was obtained only because of the off-center trim position of the ailerons, and for the same reason they were correspondingly deficient in right rolls. At higher speeds, as the trim position of the ailerons approached the neutral position, the maximum values of $pb/2V$ in right and left rolls approached each other at values less than 0.07.

In the cruising condition, an average value of $pb/2V$ of 0.055 was the maximum achieved; at high speeds, due to stretch in the control system, the available

aileron deflection and, accordingly, the maximum $pb/2V$ obtainable were considerably reduced.

For all conditions tested, the variation of $pb/2V$ with control deflection remained essentially constant except at the lowest airspeeds; there, a marked reduction in effectiveness per unit control deflection was noted. This reduction appeared due largely to the comparatively large values of sideslip angle that occurred at the time that maximum rolling velocity was reached. The effect diminished rapidly with increasing airspeed.

In table IV the relative effectiveness of the ailerons for the cruising, combat, and landing conditions are compared at two airspeeds.

The deficient power of the ailerons was due mainly to the limited deflection range of the surfaces. The results of tests of beveled trailing-edge ailerons with increased deflection range are given in reference 1 and show a definite improvement in aileron characteristics.

4. As shown in figures 28 and 29, the variation of aileron-control force with aileron deflection for each condition tested was a smooth curve.

At low speeds and small deflections, particularly in the landing condition, the stick forces were of small magnitude (in some cases less than the friction force measured on the ground), and the ability of the control

to center itself appears from the data to be doubtful. However, since the pilots reported the controls to be satisfactory in this respect, it is likely that values of friction measured on the ground were not realized in flight and the control was actually self-centering.

The effects of flexibility in the aileron-control system are indicated by the progressive reduction in deflection of the control surfaces for a given stick deflection with increasing stick forces. This is best shown by the variation in deflection of the end points of the curves of figures 28 and 29, all of which correspond to full stick deflection; departures from the trend are due to changes in the trim positions of the ailerons.

5. Aileron stick forces were excessive for large deflections in high-speed flight. In figure 30 it may be seen that full control deflection could be obtained with the recommended stick force of 30 pounds only below approximately 220 miles per hour in the combat condition, and below 240 miles per hour in the cruising condition. For higher speeds, a 30-pound stick-force limitation results in a decrease in the values of $pb/2V$ obtainable as shown in figure 30.

II-C. Yaw due to ailerons

The maximum angles of sideslip developed as a result of full aileron deflection in the critical low-speed condition were as follows: cruising, 16.4°; combat, 13°; and landing, power off, 14.0°. The requirement of reference 2, which states that less than 20° should be developed in full aileron rolls, rudder fixed, was therefore met in these conditions.

It is of interest to note that, if the aileron effectiveness were increased to values that are considered desirable, the sideslip developed in aileron rolls would approach the specified limit of 20°.

II-D. Limits of rolling moment due to sideslip (dihedral effect).

1. The rolling moment due to sideslip was measured by recording the aileron angles required in steady sideslips. The results are presented in figures 31 through 39, inclusive. The rudder, elevator, and right aileron position, angle of bank, and aileron and rudder forces are plotted as functions of the angle of sideslip. The dihedral effect was positive in most of the conditions. Negative dihedral effect was, however, encountered in power-on sideslips to the left at low speeds (figs. 31, 32, and 37). This instability is probably due in part to an unsymmetrical distribution of the propeller slipstream over the wing. With power on at low speeds,

the slipstream over the right wing may be considerably higher than that over the left. As the angle of sideslip increases to the left, the slipstream moves farther out on the right wing, thereby increasing the left rolling moment.

In the cruising condition, there was little variation of dihedral effect with airspeed at small angles of sideslip as shown by the data in figure 39.

2. The variation of aileron stick force with angle of sideslip as determined in steady sideslip was, in all cases, small, the forces rarely exceeding 4 pounds. In the flight conditions where the aileron deflections indicated negative dihedral effect, the stick forces also indicated negative dihedral. Because of the small magnitudes of the stick forces associated with negative dihedral effect, this characteristic was not considered objectionable by the pilots.

Isolated points, where negative dihedral was indicated by the stick force but not by the aileron deflection, may be noted; but again the actual magnitudes of the forces were very small (less than the value of friction as measured on the ground).

3. The rolling moment due to sideslip was never great enough to cause a reversal of rolling velocity as a result of yaw due to ailerons, although at low speeds

(as noted in paragraph II-B-3) it resulted in perceptible reductions in the aileron effectiveness.

II-E. Rudder-control characteristics

1. The rudder control was sufficiently powerful to overcome the adverse aileron yawing moment. In all conditions tested, larger angles of sideslip were obtained with the rudder (figs. 31 through 38) than would be necessary to counteract the maximum yaw due to ailerons developed in full-deflection aileron rolls. Possible exceptions are indicated by the results of a series of rolls made to the left at 90 miles per hour in the landing condition with partial power where the records were stopped before the airplane attained its maximum angle of sideslip or maximum rate of roll; no conclusion regarding the power of the rudder to combat adverse aileron yaw can therefore be drawn for this condition.

2. As is indicated in the time histories of a typical landing and take-off (figs. 23 and 24), the rudder was sufficiently powerful to maintain directional control for these maneuvers. The rudder effectiveness was also considered adequate for satisfactory ground-handling.

3. Spin tests were not made, but during the stall tests the airplane several times rolled off into an incipient spin; in every case the rudder, in conjunction with the other controls, easily provided the forces necessary for recovery.

4. The slopes of the rudder position and force curves, shown in figures 31 through 38, indicate that the airplane meets the requirement of reference 2 that right and left rudder forces should always be required to hold corresponding deflections from trim.

5. In none of the conditions discussed in the preceding four paragraphs did the required rudder forces exceed 180 pounds, thereby meeting the requirements of reference 2. Figure 39 shows the variation of rudder force per degree sideslip with airspeed.

II-F. Yawing moment due to sideslip (directional stability)

1. As is stated under paragraph II-C, the maximum angles of sideslip developed in aileron rolls with rudder fixed in the critical low-speed conditions were less than 20° and hence satisfied the requirement of reference 2.

2. The yawing moment due to sideslip was such that the rudder always moved in the correct direction, that is, to the right in left sideslips, and vice versa. From figure 39, showing summarized results for the sideslips in the cruising condition, it may be seen that the directional stability is of reasonable magnitude, nearly 1° of rudder deflection being required per degree sideslip throughout the speed range.

3. It may be seen in the sideslip characteristic curves (figs. 31 through 38) that the rudder force increases in the correct direction with sideslip angle for all conditions. This assures that the airplane will tend to return to its trim position if the rudder is released; the effects of friction in the rudder-control system would prevent an immediate return to complete trim (fig. 27).

Reversal of the rudder forces was not encountered in any of the sideslip tests.

4. Although no requirement has been established in reference 2 regarding permissible rudder-force variations with airspeed, several cases have recently been encountered where this force variation has been objectionably high. Tests of the XP-51 indicate it to be fairly satisfactory in this respect; the measured values of rudder force being as follows:

a. With the rudder force trimmed to zero at an indicated airspeed of 220 miles per hour with rated power, the airplane can be dived to 400 miles per hour with a rudder force of approximately 50 pounds. Cutting the throttle at 400 miles per hour requires a rudder force of about 100 pounds.

b. With the rudder force trimmed to zero at an indicated airspeed of 160 miles per hour with

rated power, a force of 100 pounds is required at 400 miles per hour. Cutting the throttle from this condition requires a force of about 175 pounds.

II-G. Cross-wind force characteristics

The variation of cross-wind force with sideslip was always in the correct direction as shown by the angle of bank required to hold the airplane in a steady sideslip (figs. 31 through 38). The side force gradient of the XP-51 was slightly smaller than that of any pursuit-type airplane tested previously.

II-H. Pitching moment due to sideslip

The pitching moment due to sideslip is shown by the variation of elevator angle with sideslip angle in the steady sideslip tests (figs. 31 through 38). In all conditions of flight, the pitching characteristics in sideslips were desirably small and in substantial compliance with the requirements of reference 2. In all conditions of flight except the gliding condition, less than 1° change in elevator angle was required to maintain longitudinal trim at 110 percent of the minimum speed when the rudder was moved 5° right or left from its trim position. The actual deflections required were of magnitude comparable with those noted on airplanes of similar type.

II-I. Power of rudder and aileron trimming devices

1. The rudder trim tab was sufficiently powerful to reduce the trim forces to zero at any airspeed from 120 percent of the minimum speed to the maximum speed in the cruising condition, thereby satisfying the requirements of reference 2. While the power of the tab was not investigated specifically, it appeared adequate to the pilot under all conditions.

The aileron and rudder forces required for trim for all conditions of flight may be found in the static stability curves (figs. 10 through 13, inclusive); the aileron trim tab was neutral for each condition while the setting of the rudder trim tab is noted.

2. Unless changed manually, the trimming devices would retain their settings indefinitely.

III. Stalling Characteristics

The stalling characteristics of the airplane were determined in the gliding, cruising, landing, climb, wave-off, and take-off conditions of flight. In general, these conditions were investigated with the following arrangements:

1. Wing and fuselage gun ports covered with doped fabric (clean wing)(figs. 2 and 40).

2. Two 20-millimeter-gun mock-ups installed in each wing, and fuselage gun ports covered with doped fabric. Two types of fairing were tested on the

20-millimeter guns (figs. 41(a) and 41(b)). (Since no difference in stalling characteristics could be determined between the two fairings, the following discussion will be considered as applying to either.)

3. Wing and fuselage gun ports open.

The tests were made by taking continuous instrument records as the airspeed was decreased while the wings were held laterally level. Observations were made of tufts fastened to the upper surface of both wings. At the first sign of the stall, the controls were, in some cases, fixed; in other cases the elevator control was pulled farther back while either the rudder or aileron control was used independently in an attempt to maintain a level attitude. Stalling speed was taken as the speed at which pronounced lateral instability was encountered.

Time histories of several typical stalls are presented in figures 42 through 55, and are discussed in the following paragraphs. Stalls were made with the center of gravity in both forward and aft positions, but, since no difference could be detected in the stalling characteristics, this factor is not included in the discussion.

Values of maximum lift coefficients, based on data obtained in the stall tests, are presented in the following table. These values were determined from tests in the various conditions wherein the approach to the stall was

very gradual and are not in general consistent with the minimum speeds shown in the time histories of stalls presented in figures 42 through 55. For the stalls shown in these time histories, there are several cases where the approach to the stall is too abrupt to permit use of the data in calculating maximum lift coefficients for steady flight.

Flight condition	Wing condition	Maximum lift coefficient
Gliding	clean	1.5
Gliding	20-millimeter guns	1.5
Cruising	clean	1.6
Cruising	20-millimeter guns	1.6
Landing	clean	1.9
Landing	20-millimeter guns	1.8
Take-off Wave-off	Run out of rudder before minimum speed was reached	

Gliding condition. - All stalls in the gliding condition of flight were characterized by a breakdown of the air flow along the trailing edge of the wing, extending over the middle half of each semispan. As the speed was further decreased, the air-flow breakdown spread spanwise and forward, the extent of the breakdown being somewhat greater over the right than over the left wing.

In the clean-wing condition, the stall was first evidenced as a mild right roll which was easily corrected and hardly of sufficient magnitude to serve as a stall warning. If, ignoring this warning, the stick was moved a little farther back while holding the other controls fixed (fig. 42), a mild left roll would occur followed by a rapid right roll which developed into an oscillatory spiral.

Control could be maintained successfully by means of the ailerons alone (fig. 43) until the stick had been pulled back approximately 2 inches from the position at the stall. At that time an aileron reversal intended to check a roll resulted only in an increase in rolling acceleration.

Use of the rudder alone to maintain control (fig. 44) failed to prevent the airplane from rolling to the right, although it did hold the rate of roll to a small value. With the stick somewhat over 2 inches aft of the stall position and the airplane at an angle of bank to the right of about 60° (according to the pilot's observation) the airplane suddenly snapped over into a spin to the left. Recovery was immediately effected by relieving the elevator and reversing the rudder and ailerons.

With the 20-millimeter-gun mock-ups installed, the initial warning roll, which occurred at about the same speed as that for the clean wing, was again to the right and was accompanied by a mild tug on the stick to the right. The succeeding left roll was considerably slower than the corresponding right roll for the clean wing even though the elevator control was moved farther back (fig. 45).

Attempts to control the motions in the stall by use of the ailerons and rudder independently gave results similar to those for the clean wing. Apparently because of the difficulty in coordinating sideslip and bank experienced in

the particular run, oscillations of fairly large amplitude were noted when the rudder was used alone. As shown in figure 46, however, it was possible by the use of both ailerons and rudder to control the airplane for some time with the stick full back. It should be noted in this connection that the condition of elevator full back may not always be the most critical from a control standpoint. Experiences with other airplanes indicate that in some cases control may be quite difficult just beyond the stall, but when the stick is moved full back a fully stalled condition is attained which is more stable laterally and hence easier to control.

Figure 47 shows a typical stall in the gliding condition with the gun ports open.

In all cases recovery from the stall could be effected promptly by moving the elevator control forward.

Cruising condition. - The first evidence of flow breakdown in the cruising condition with the clean wing was noted at the root of the left wing. As the speed was further reduced, the air-flow breakdown spread spanwise along the trailing edge of both wings and then forward near the wing tips.

The imminence of the stall was indicated by a light aileron snatching and a mild roll to the right. A slight further movement of the stick back caused a faster roll to the right (fig. 48) which was checked when the stick was eased forward.

As seen in figure 49, control beyond the stall was effectively maintained for some time by the use of ailerons, aided somewhat by inadvertent use of the rudder. Because of lag in the application of rudder, a considerable angle of bank was achieved before the rudder, applied alone, reversed the roll (fig. 50).

With the 20-millimeter-gun mock-ups installed the initial left-wing root stall was absent, but the general progress of the air-flow breakdown over the wing was similar to that of the clean wing. Also, in addition to the aileron snatching, a mild buffeting of the tail was noted before uncontrolled motions ensued. The initial motions in the stall were a mild lateral oscillation which gave way to a violent roll-off only after the elevator control had been pulled about 2 inches farther back (fig. 51). At this point the rudder alone was ineffective in preventing a spin break although it did reverse the direction of the break (fig. 52).

With the gun ports open, the stalling characteristics were approximately the same as those for the condition with 20-millimeter guns. Warning in the form of tail buffeting existed and the ensuing motions were very mild.

Recovery from the stall or from incipient spins could always be effected by normal use of the controls.

Landing condition. - In the landing condition with the clean wing the air-flow breakdown spread abruptly over nearly

all the right wing and the tip of the left wing. No warning was noted before the airplane rolled to the right, slowly at first, but at an increasing rate as the stick was moved back. With the lateral controls fixed, the roll developed into a turn (fig. 53). By the use of either rudder or aileron control it was possible to check and correct the airplane movement, but such control was possible only for a limited time, after which the airplane tended to roll violently.

With 20-millimeter-gun mock-ups installed, the flow breakdown started at the ailerons on both sides at about 5 miles per hour above the stalling speed. The stall moved forward over both wings near the mid-span points, progressing farther on the right wing than on the left. In no case was the spread as great as that of the clean-wing condition. There was no warning of the stall, but the airplane with controls fixed rolled slowly right into a spiral of varying tightness or oscillatory character depending on the elevator position (fig. 54).

By using the ailerons, it was possible to maintain control for a considerable period of time with the stick almost full back. The rudder was also effective in maintaining control, but because the rudder controls the motions indirectly, that is, through control of the sideslip, the movements of the airplane in the stall were more violent than were those experienced with aileron control. By the use of both ailerons and

rudder, control was maintained successfully and the lateral motions were held to small amplitudes with the stick full back.

With the gun ports open, the flow breakdown was confined to the inboard half of the right wing and was characterized by no warning and a very mild and easily controllable roll-off.

Wave-off condition. - In the wave-off condition a very mild lateral oscillation began just before the rudder and aileron deflections required for trim reached their limits of travel. Depending on how well the rapidly changing trim requirements were followed by control movements, the airplane would then either continue to oscillate mildly in a turn against the controls (fig. 55) or roll off rapidly to the left. Maximum rudder deflection was reached at airspeeds above the stalling speed.

Similar characteristics were obtained in stalls with the 20-millimeter-gun mock-ups and with the gun ports open.

The lightening of rudder-control forces as the stall progressed is a characteristic feature of the stalls in this condition.

Take-off condition. - The characteristics in the take-off condition were very similar to those in the wave-off condition.

Stalls in turns. - The stalling characteristics of the airplane were investigated in 180° turns in the cruising

conditions of flight, and typical time histories of these turns to the right are shown in figures 14, 16, and 20. No marked differences in characteristics between right and left turns could be detected.

No stall warning other than that given by the stick force and position gradients indicated in figure 21 was noted. In the stall, however, considerable tail buffeting occurred, as shown by the instrument records.

When the stall occurred the airplane invariably tended to pitch down and roll. The direction of the initial roll in the stall was inconsistent and the rate of roll varied with the wing condition; that is, with the clean wing (gun ports covered) and in right turns with the 20-millimeter-gun mock-ups, the roll-off was into the turn and much faster than it was with the gun ports open and in left turns with the 20-millimeter-gun mock-ups.

In general, the motions of the airplane when stalled under accelerated conditions are considered to make the airplane unsatisfactory as a gun platform in this region of flight, but, nevertheless, the stalling characteristics compare favorably with those of other modern fighters.

CONCLUSIONS

As a result of flight tests, the following conclusions may be stated regarding the flying qualities of the North American XP-51 airplane:

1. The short-period longitudinal oscillation disappeared within one cycle in all conditions tested.

2. The airplane had positive longitudinal stability forward of the following center-of-gravity positions for the conditions noted:

Flight condition	Stick fixed, percent M.A.C.	Stick free, percent M.A.C.
Cruising	30.8	30.5
Gliding	34.2	34.4
Landing	31.2	32.5
Climbing	30.6	31.5

3. As determined from steady turning flight, the longitudinal-stability characteristics in maneuvers were as follows for the cruising condition of flight:

Center-of-gravity position, percent M.A.C.	Stick motion required to stall from $C_L = 0.2$, inches travel of top of stick	Stick-force gradient, lb per g
25.5	2.4	8.3
28.9	1.2	4.4

4. The elevator control was adequate for take-off and landings with the center of gravity as far forward as 21.5 percent of the mean aerodynamic chord.

5. The longitudinal trim changes due to power and flap variations were desirably small, being less than 6 pounds for all conditions tested.

6. The elevator trim tab was sufficiently powerful to trim the airplane as desired in the various flight conditions.

7. The control-free lateral oscillations damped to one-half amplitude within one cycle for all conditions tested. No tendencies for the rudder or aileron controls to oscillate were observed.

8. Because of limited deflection range, the aileron control did not meet the effectiveness requirements for speeds up to 0.8 of the maximum level-flight speed. The control was particularly unsatisfactory at low speeds. Although no requirements have been set up for lateral control at speeds above 0.8 of the maximum level-flight speed, it is believed that the control available in the NF-51 was satisfactory in the diving-speed range.

9. For the available aileron deflection range, the aileron yaw was everywhere within the specified limit of 20°.

10. The dihedral effect was positive except in low-speed sideslips to the left with power on. The negative dihedral effect was not large enough to be disturbing to the pilot.

11. The rudder power was adequate to counteract the yaw due to the ailerons and to maintain directional control during take-offs and landings. The rudder forces required were less than the recommended upper limit of 180 pounds. The variations of rudder force with airspeed and engine power in dives to high speed were larger than desirable. The maximum forces, however, were less than 180 pounds in the conditions tested.

12. The directional stability characteristics were satisfactory. No tendency for rudder force reversal existed in any flight condition.

13. The pitching moment due to sideslip was desirably small.

14. The power of the rudder and aileron trim tabs was adequate.

15. Requirements for satisfactory stalling characteristics were met in all respects except for stall warning. In all conditions, lateral instability occurred as the first indication of stalling. In the steady flight conditions, the instability was in the form of a mild roll. In the accelerated condition, the instability was in the form of a lateral oscillation combined with pitching and, although enough control was available for preventing a complete roll off and change in direction, it is thought such motions would make the airplane unsatisfactory as a gun platform in this region of flight. In spite of these characteristics, it is considered that the stalling characteristics compare favorably with those of other contemporary fighters.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 13, 1943.

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1. White, M. D., and Hoover, Herbert H.: Flight Tests of Modification to Improve the Aileron Control Characteristics of a North American XP-51 Airplane (A.C. No. 41-38). NACA MR, June 20, 1942.

2. Gilruth, R. R.: Requirements for Satisfactory Flying Qualities of Airplanes. NACA ACR, April 1941.

3. Gilruth, R. R., and Turner, W. N.: Lateral Control Required for Satisfactory Flying Qualities Based on Flight Tests of Numerous Airplanes. NACA Rep. No. 715, 1941.

TABLE I

CONTROL FRICTION FORCES, XP-51 AIRPLANE

[As measured on ground with no load on surfaces]

Control	Elevator		Aileron			Rudder[1]		
Direction of force	Up	Down		Left	Right		Left	Right
Frictional force, lb	1.4	1.4	Near neutral	1.8	1.8	Near neutral	11	15
			Near maximum	6.0	4.6	Near maximum	13	15

[1]Rudder connected to tail wheel operating mechanism with tail wheel unlocked.

TABLE II

LONGITUDINAL-STABILITY CHARACTERISTICS

Condition	Center-of-gravity positions corresponding to neutral longitudinal stability	
	Stick fixed, percent M.A.C.	Stick free, percent M.A.C.
Cruise	30.8	30.5
Glide	34.2	34.4
Landing	31.2	32.5
Climb	30.6	31.5

TABLE III

LONGITUDINAL TRIM CHARACTERISTICS

Condition	Change in elevator trim angle from cruising condition, deg; 120 mph; c.g. approx. 24.9 percent M.A.C.	Change in elevator control force from cruising condition, lb; 120 mph; c.g. approx. 24.9 percent M.A.C.	Change in elevator angle for trim from windows closed to windows open, deg	Change in elevator trim angle for 5° change in elevator trim tab position, deg	Change in elevator trim angle from scoop neutral (partially open) to		
					Scoop full open, deg	Scoop closed, deg	Scoop closed with deflector down, deg
Cruising	0	0	0.8 up	0.7	0.5 up	0.1 down	--------
Gliding	1.6 up	0.1 pull	------	0.7	------	--------	0.1 down
Climbing	0.3 down	0.3 push	------	0.8	0.5 up	--------	--------
Landing	1.5 up	1.8 pull	------	0.6	------	--------	--------
Landing approach	3.1 up	5.5 pull	------	---	------	--------	--------
Take-off, flaps up	0.1 up	2.4 pull	------	---	0.5 up	--------	--------
Take-off, flaps 20° down	1.1 up	3.3 pull	------	---	0.7 up	--------	--------
Wave-off	0.4 down	2.6 pull	------	---	------	--------	--------

TABLE IV

RELATIVE EFFECTIVENESS OF AILERONS FOR 15°

TOTAL AILERON DEFLECTION, XP-51 AIRPLANE

Condition and flap position	Direction of roll	144 mph		95 mph	
		$\frac{pb}{2V}$	Relative effec-tiveness, percent	$\frac{pb}{2V}$	Relative effec-tiveness, percent
Cruising, flaps up	Right	0.0450	100	0.0375	100
	Left	.0460	100	.0390	100
Combat, flaps 20° down	Right	.0520	115	.0410	109
	Left	.0536	116	.0433	111
Landing, flaps 50° down	Right	.0383	85	.0315	84
	Left	.0374	81	.0310	80

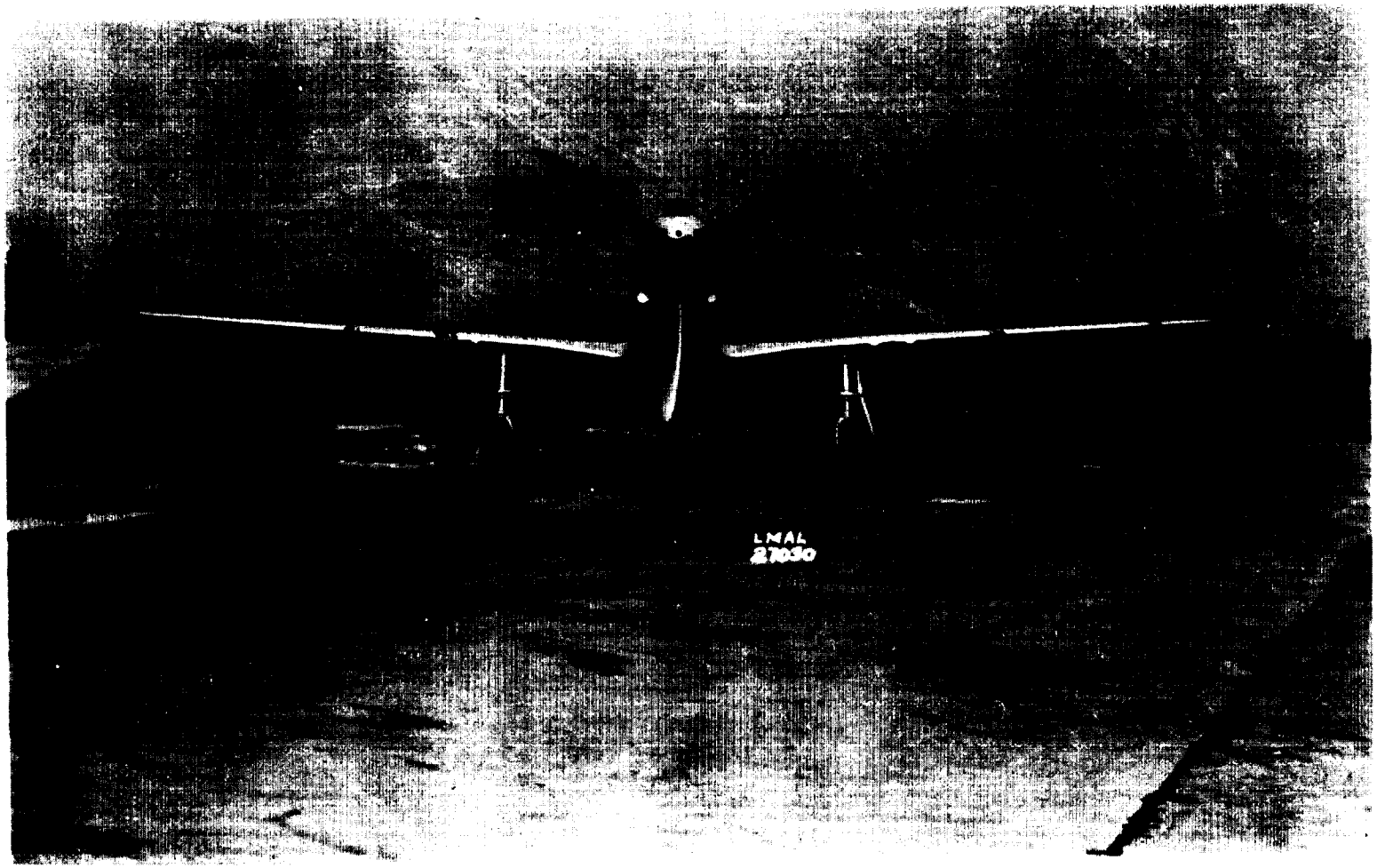

Figure 1.- Front view of North American XP-51 airplane.

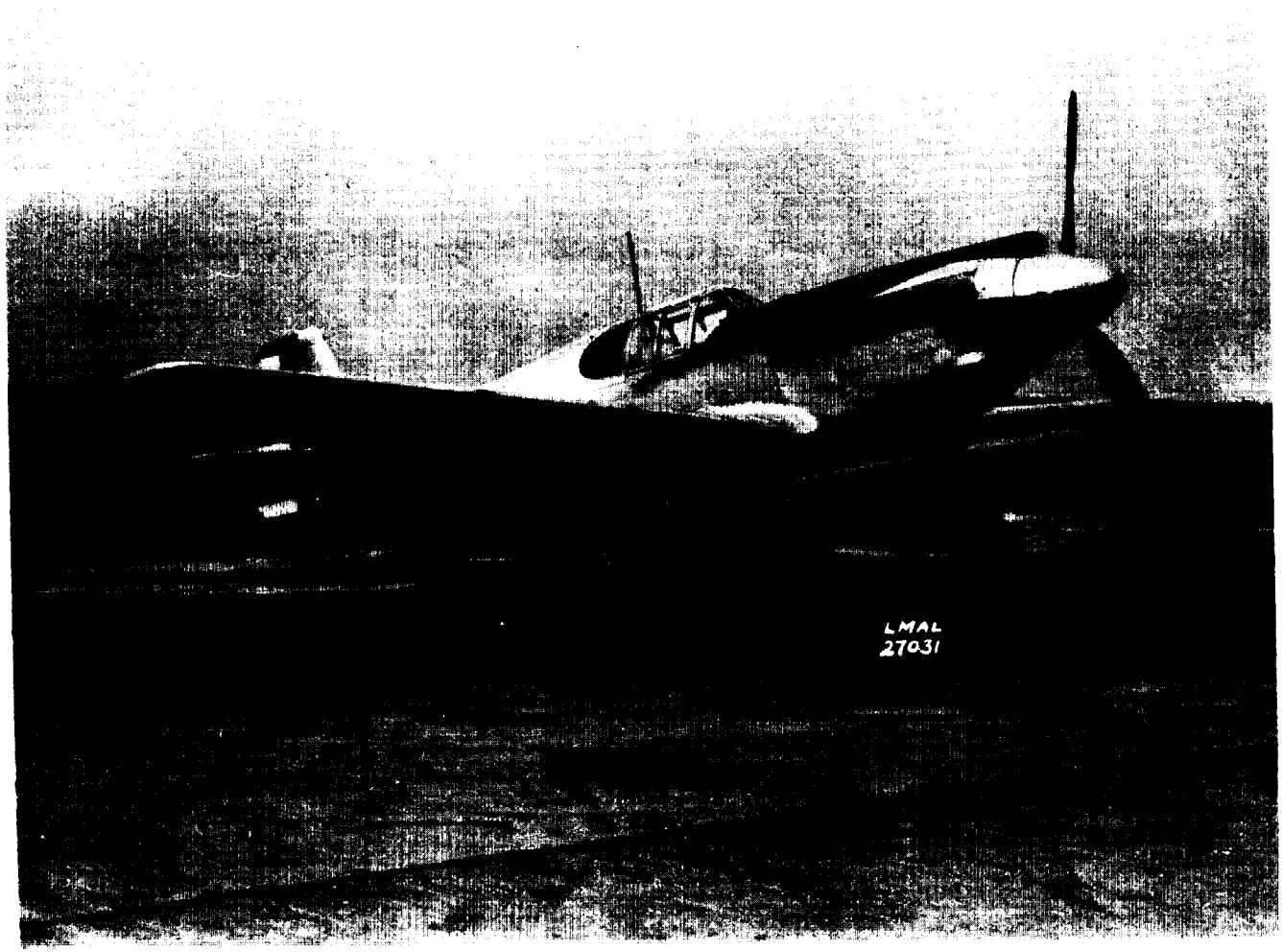

Figure 2.- Three-quarter front view of North American XP-51 airplane.

Figure 3.- Three-quarter rear view of North American XP-51 airplane.

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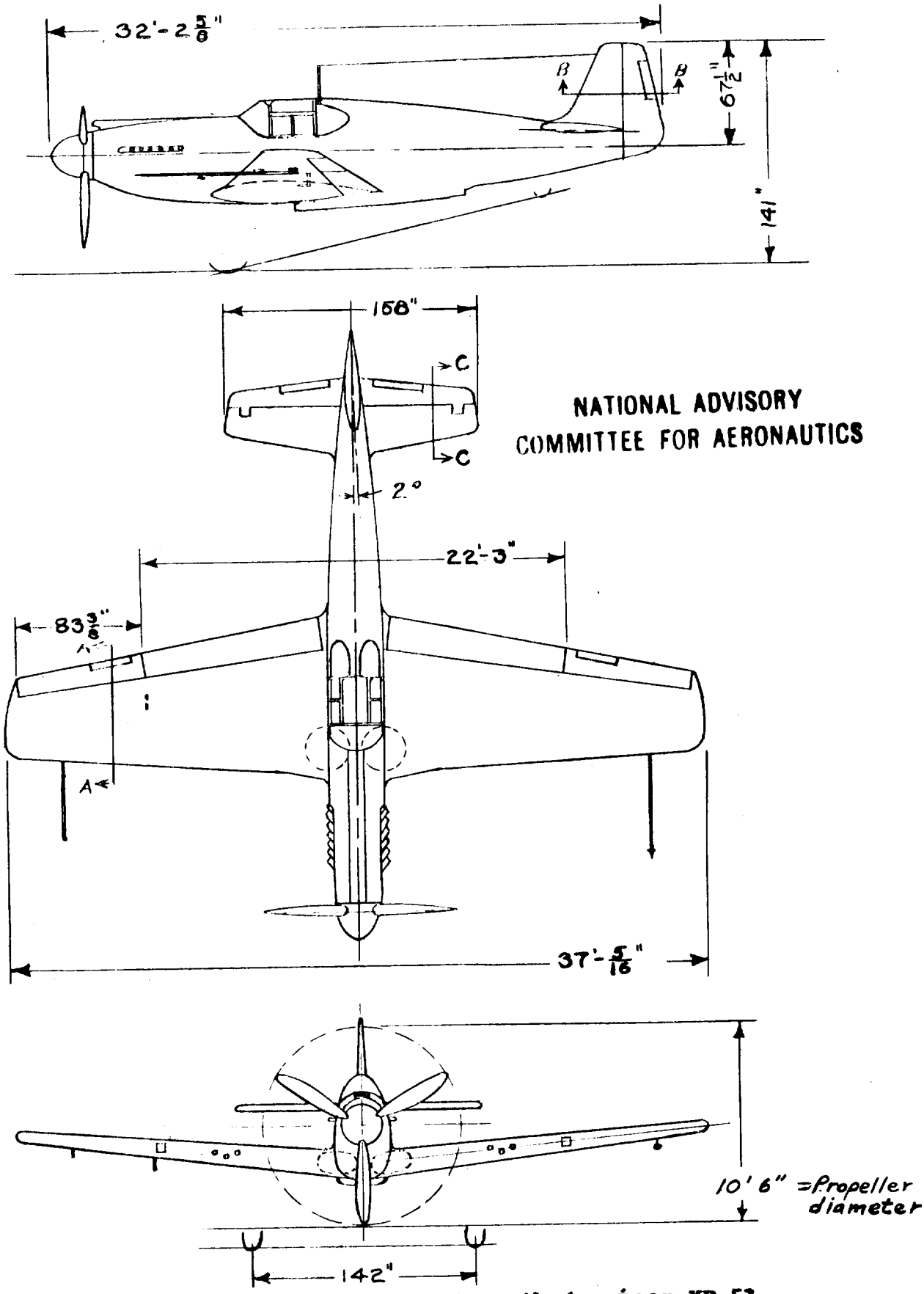

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Figure 4 — Three-view Drawing of North American XP-51 Airplane

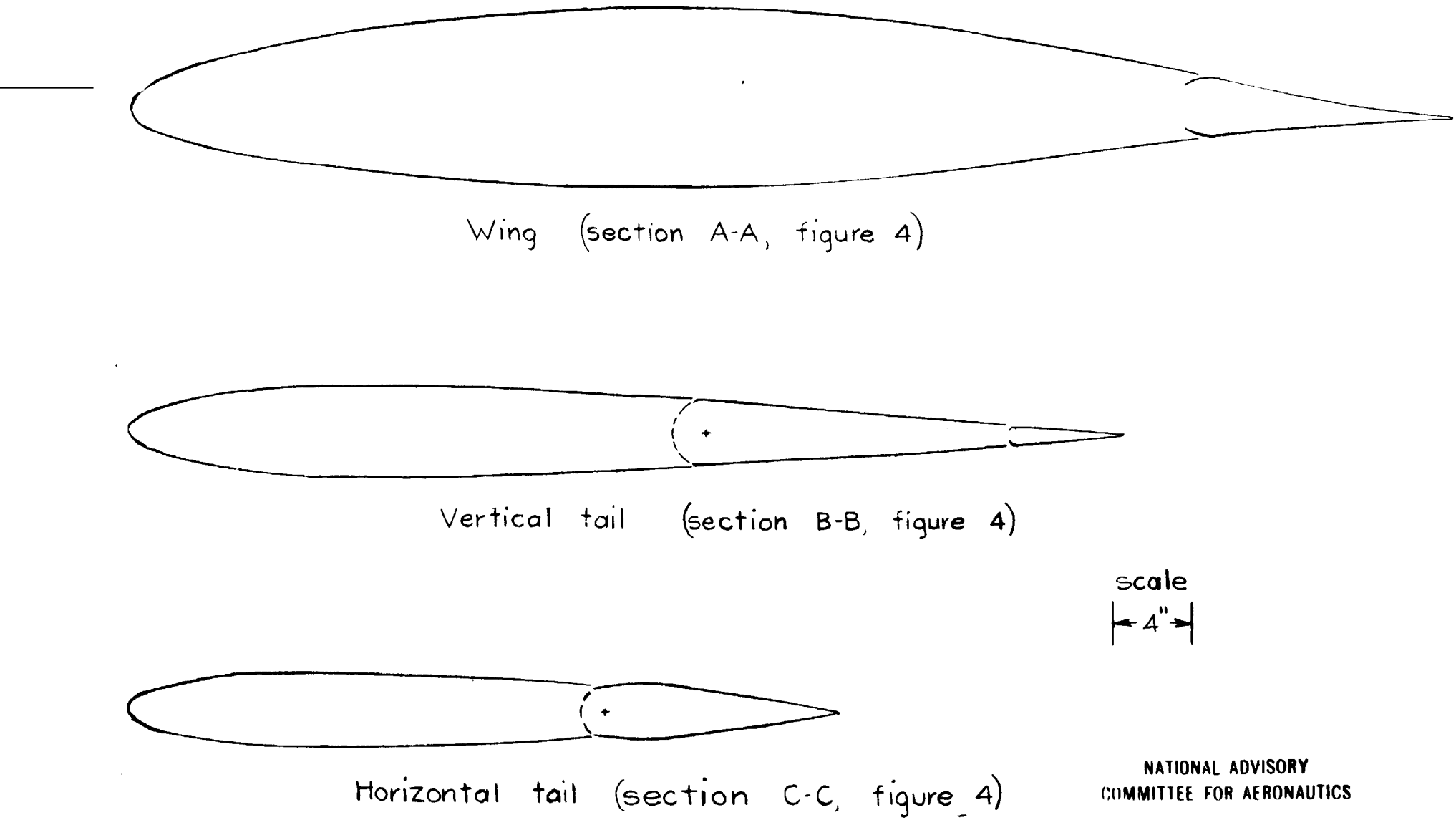

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Figure 5.- Typical sections of XP-51 wing and control surfaces.

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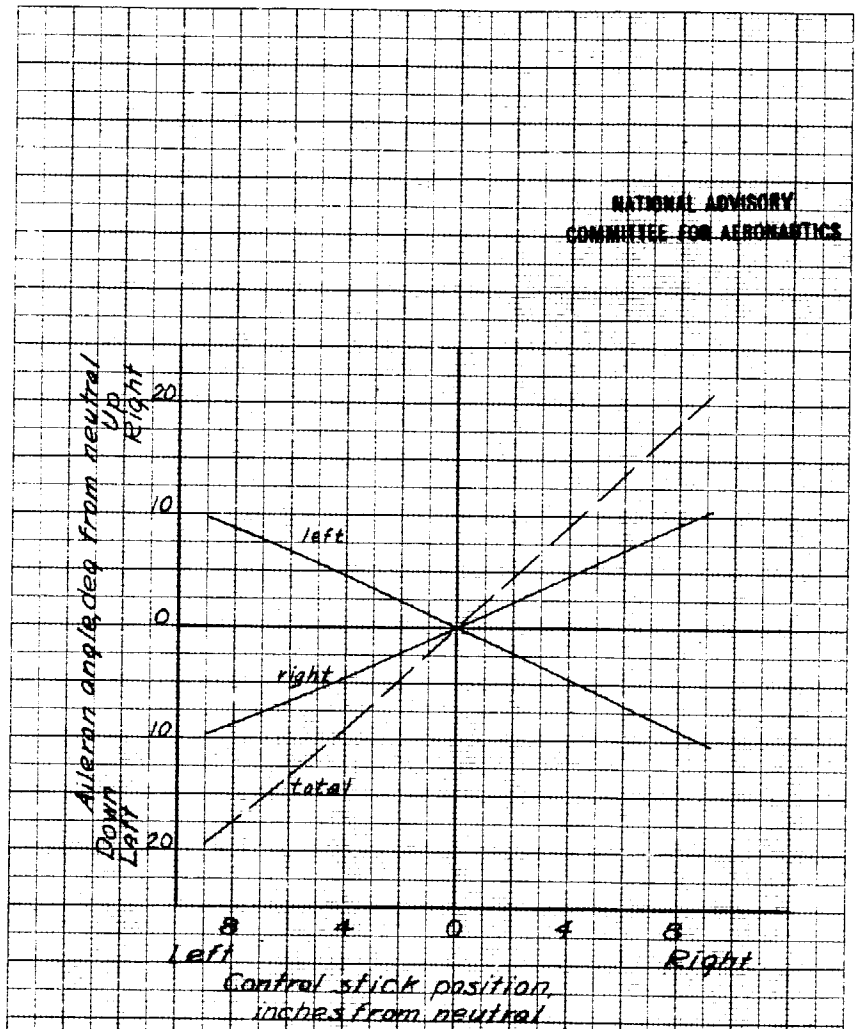


Figure 6 - Relation Between Movements of Ailerons and Position of Stick Grip. XP-51 Airplane.

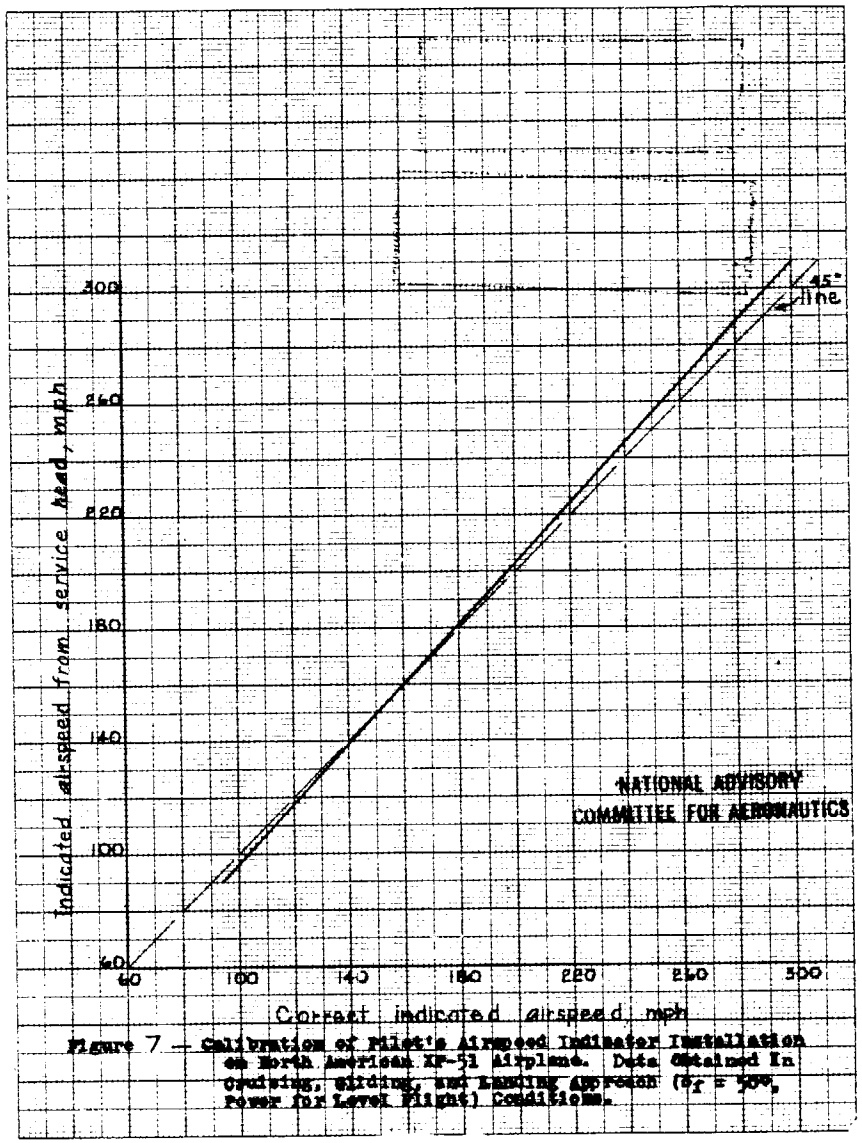
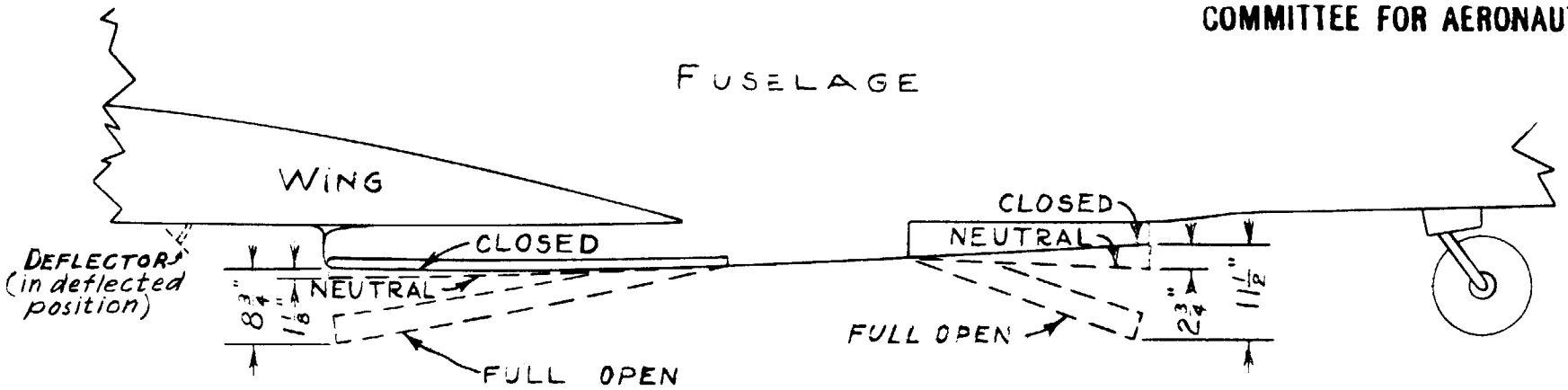
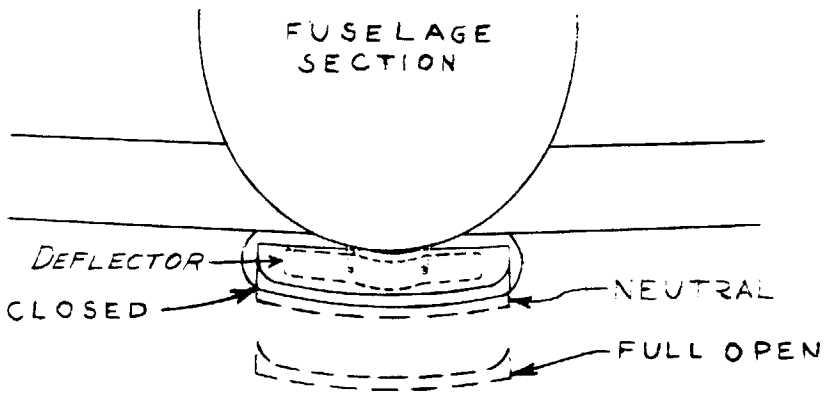


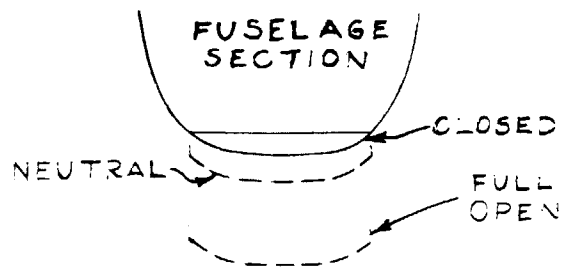
Figure 7 - Calibration of Pilot's Airspeed Indicator Installation on North American XP-51 Airplane. Data Obtained In Cruising, Gliding, and Landing Approach (δ_f = 50°, Power for Level Flight) Conditions.



SIDE VIEW, SHOWING ENTRANCE AND EXIT RADIATOR SCOOPS



FRONT VIEW, SHOWING FRONT SCOOP



REAR VIEW, SHOWING REAR SCOOP

Figure 8 — Views of XP-51 Radiator Scoop in Various Positions.

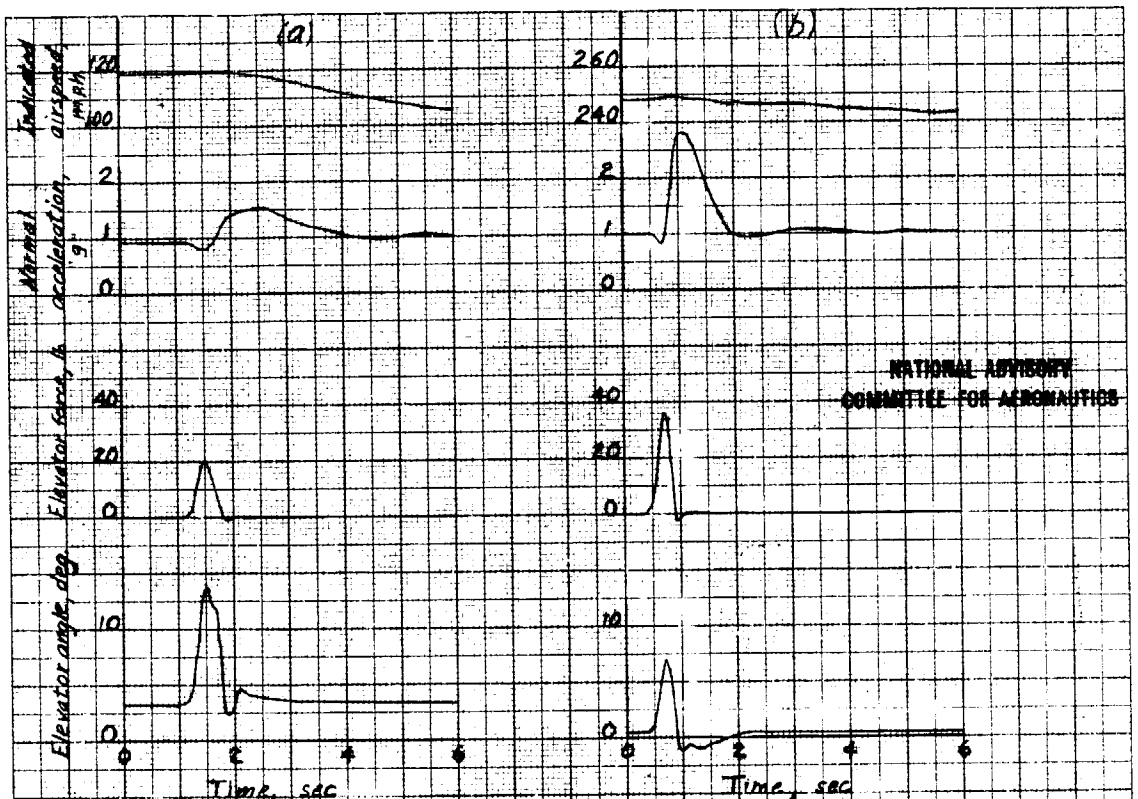


Figure 9 — Time Histories of Typical Short-Period Longitudinal Oscillations of XP-51 Airplane in Cruising Condition at (a) 119 miles per hour and (b) 248 miles per hour. (Center of Gravity at 25.1 percent M.A.C.)

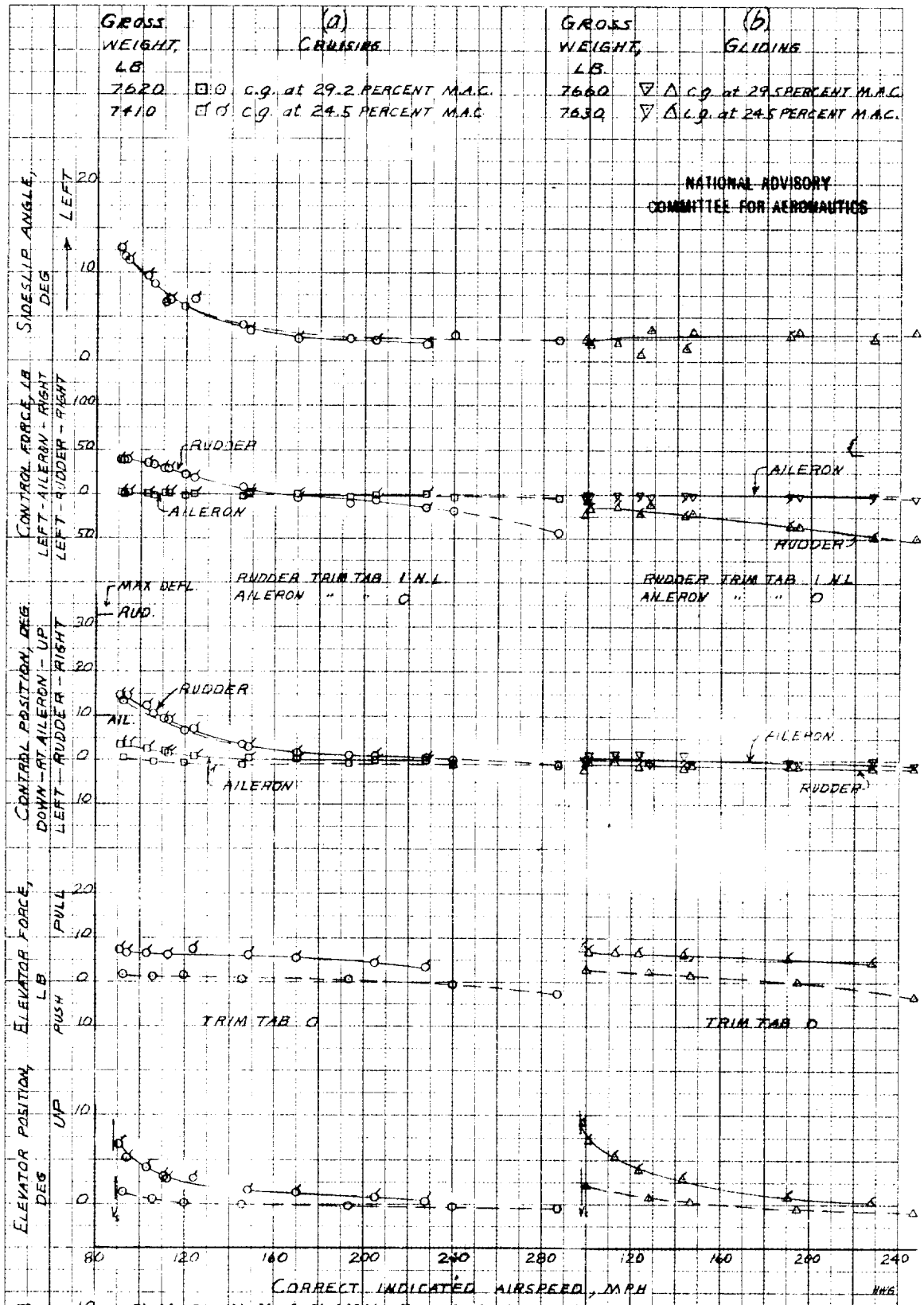


Figure 10. — Static Longitudinal-Stability Characteristics of the North American XP-51 Airplane in Cruising and Gliding Condition.

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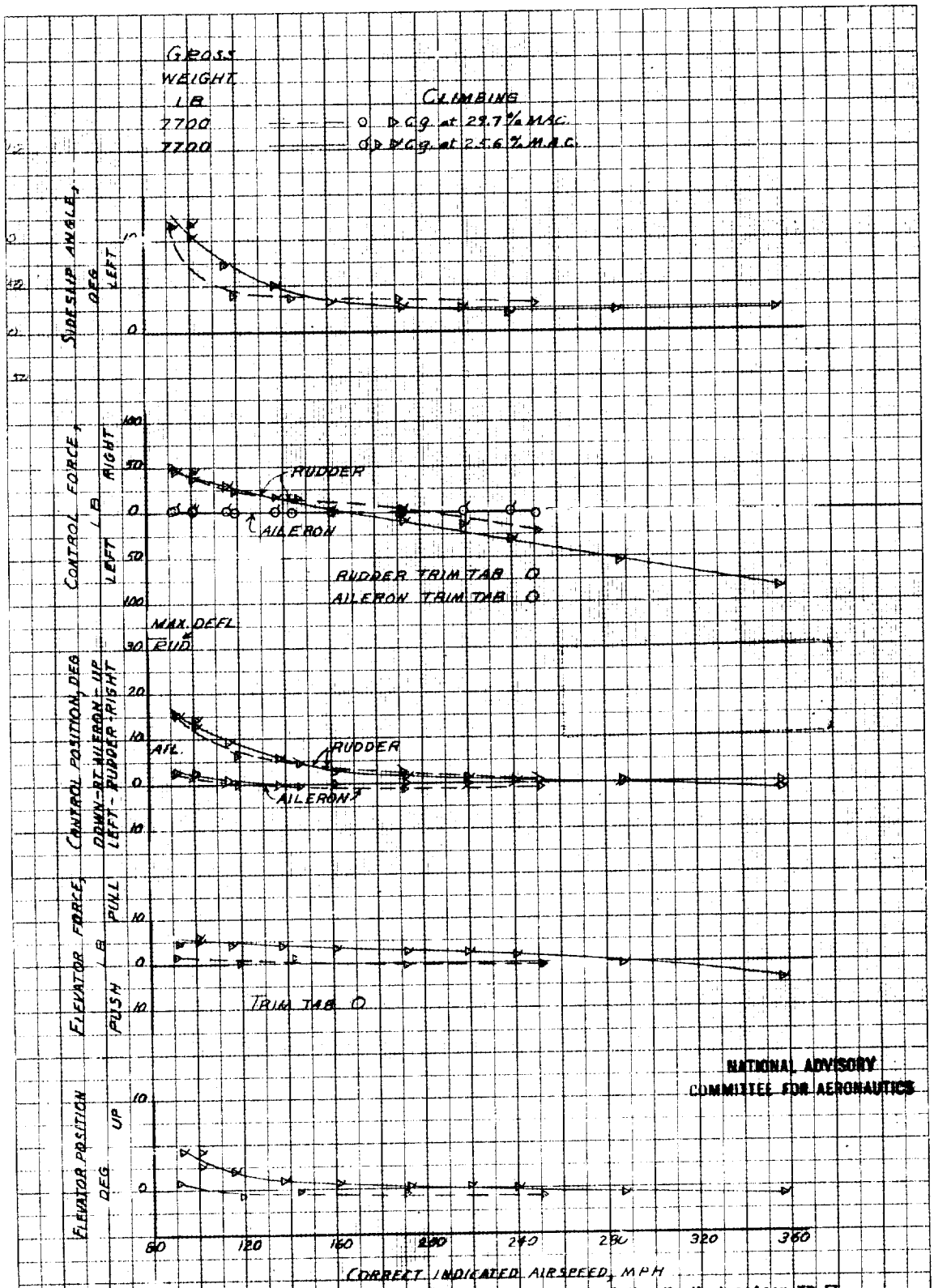

Figure 11 — Static Longitudinal-Stability Characteristics of the North American XP-51 Airplane in Climbing Condition.

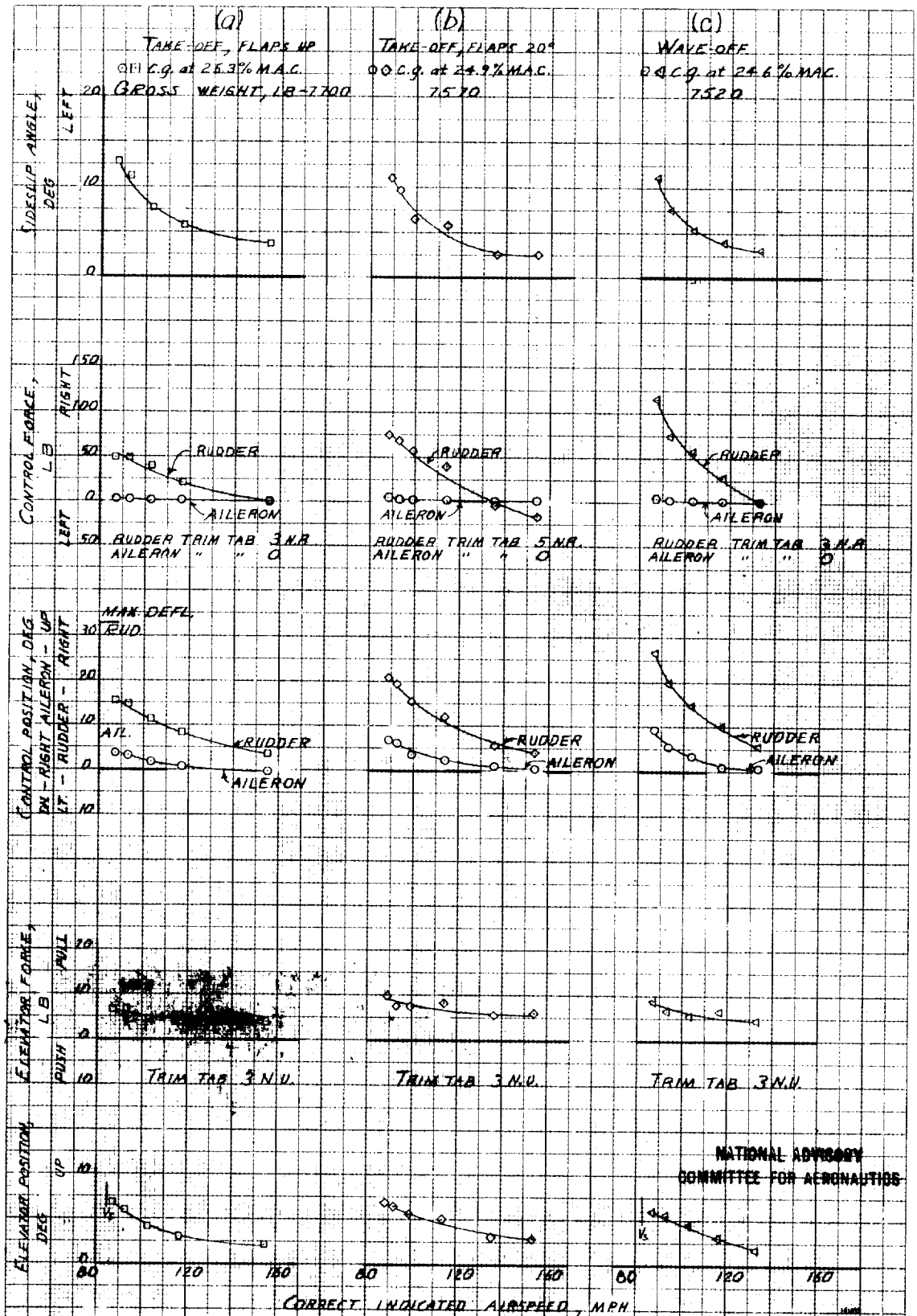

Figure 12 — Static Longitudinal-Stability Characteristics of the North American XP-51 Airplane in Take-Off Condition with Flaps Up, Take-Off Condition with Flaps Deflected 20°, and Wave-Off Condition.

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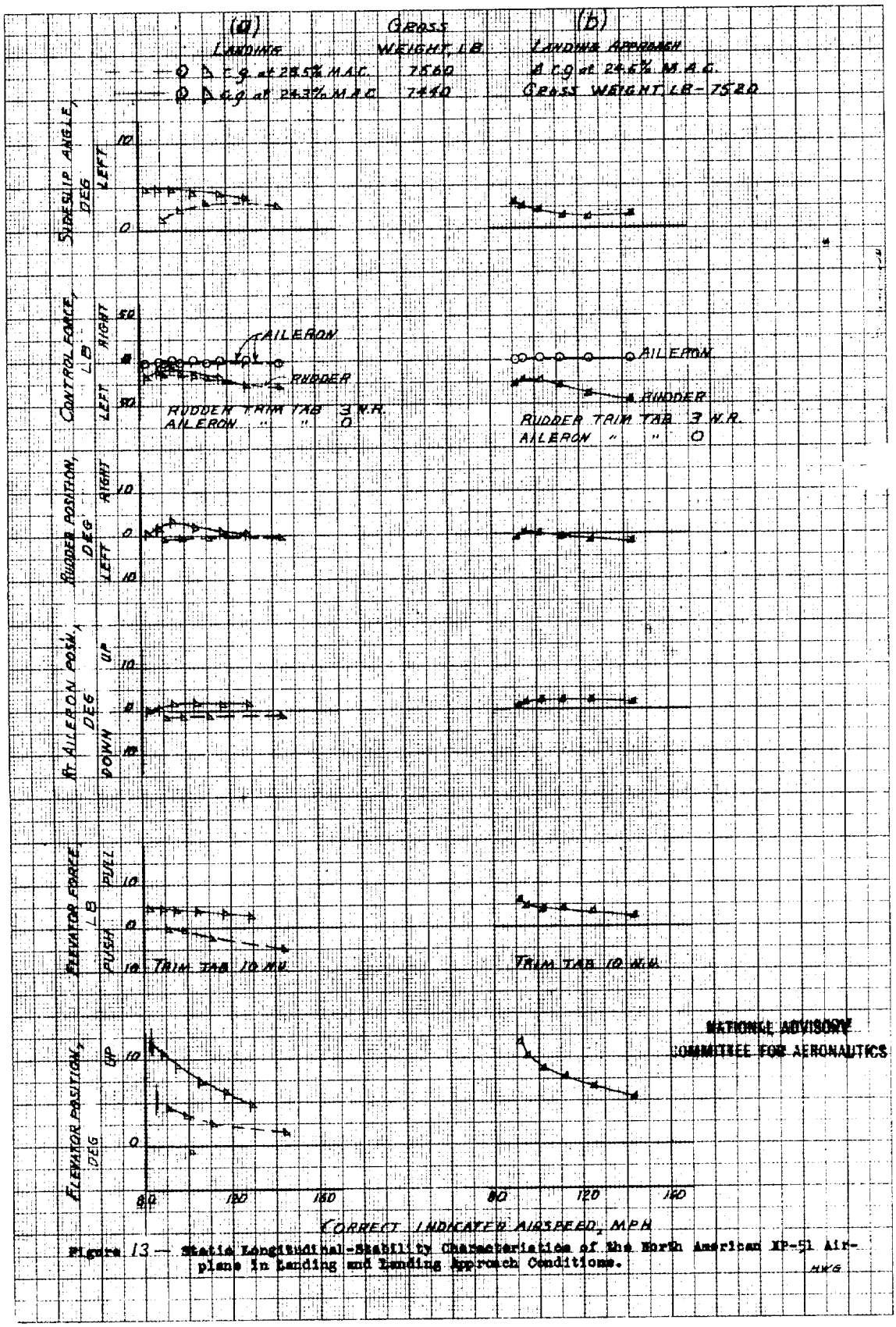

Figure 13 — Static Longitudinal-Stability Characteristics of the North American XP-51 Airplane in Landing and Landing Approach Conditions.

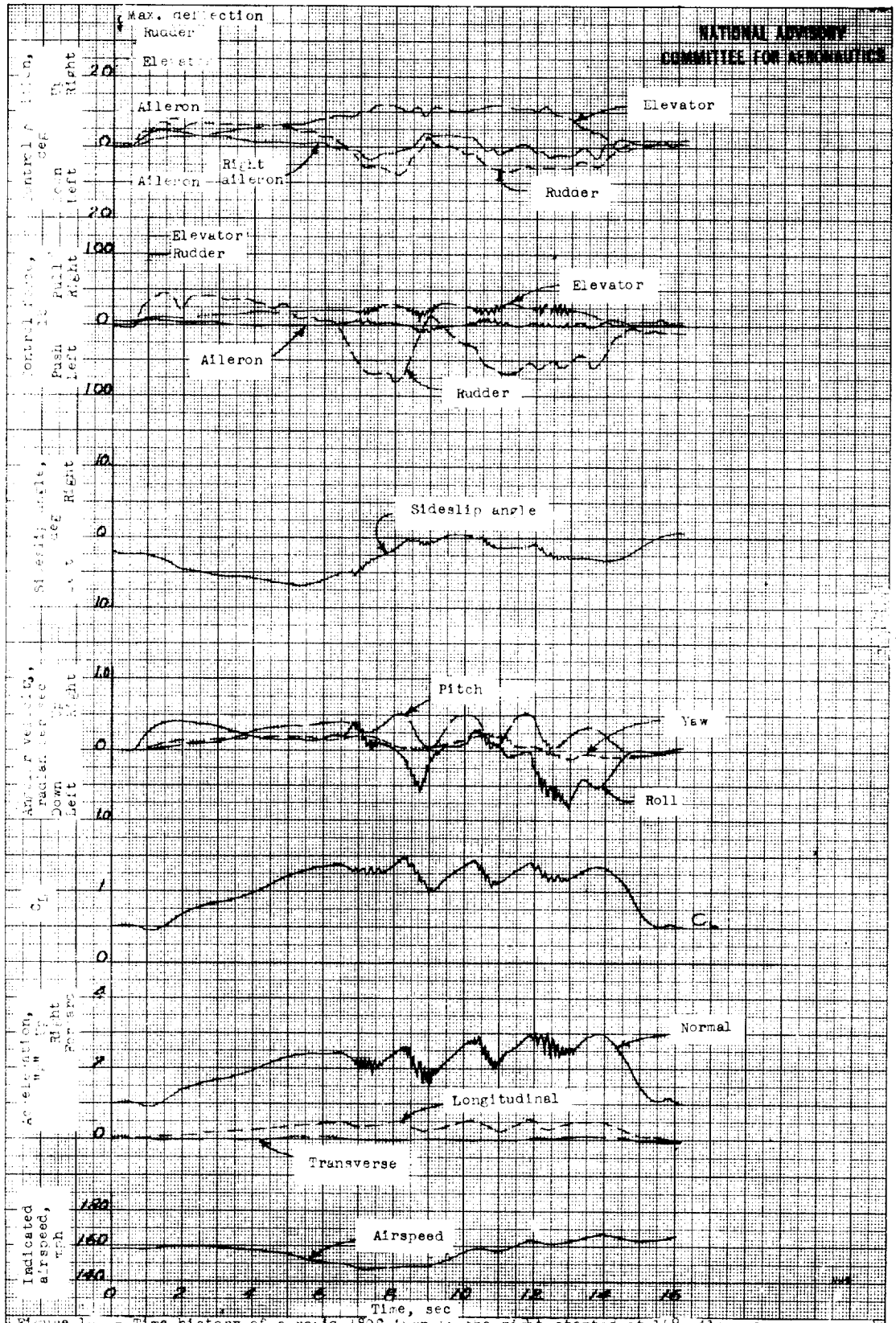

Figure 14. - Time history of a rapid 180° turn to the right started at 198 miles per hour, cruising condition, center of gravity at 25.5 percent M.A.C. Gun ports covered. XP-51 airplane.

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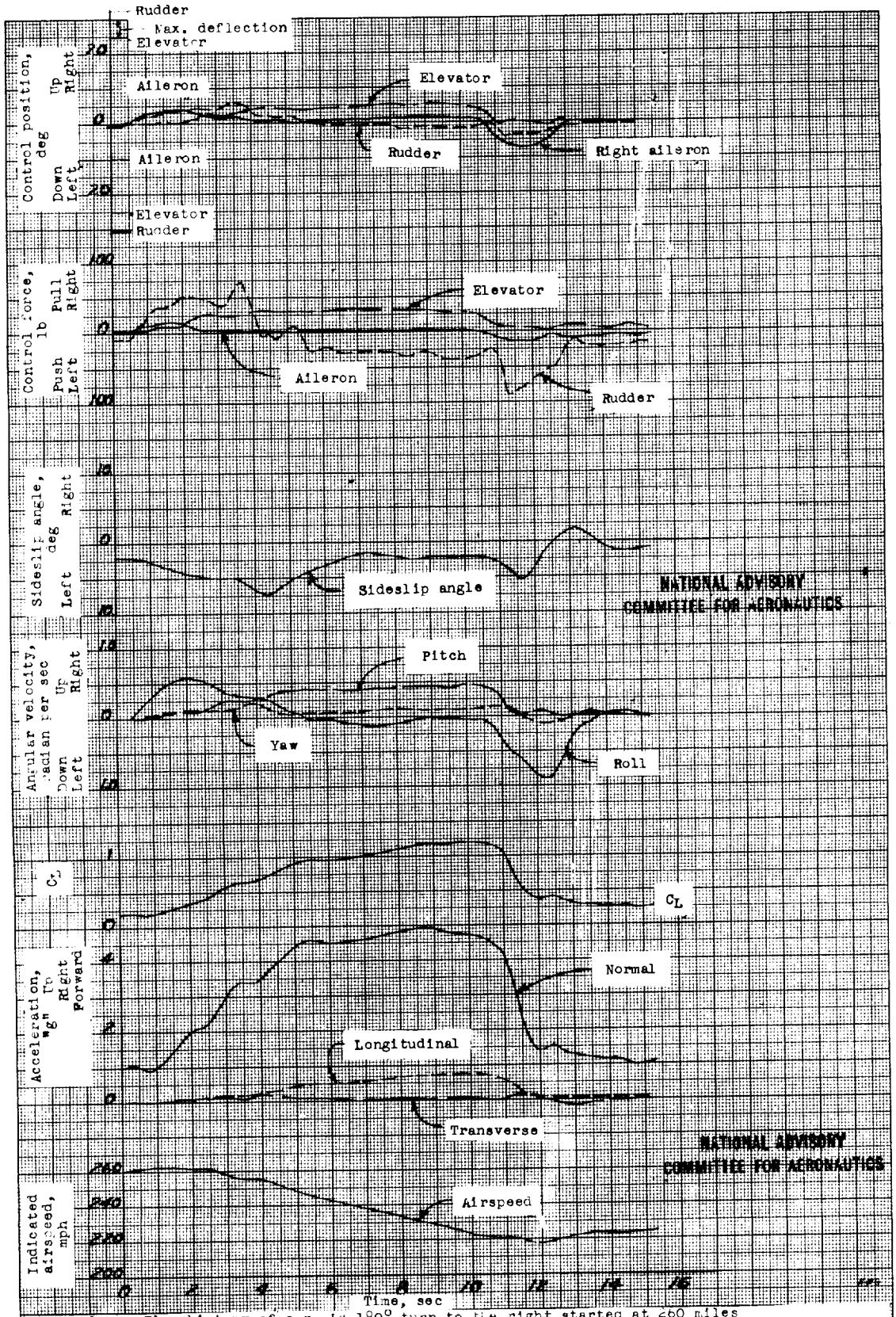

Figure 19. - Time history of a rapid 180° turn to the right started at 260 miles per hour, cruising condition. Center of gravity at 25.6 percent M.A.C. Gun ports covered. XP-51 airplane.

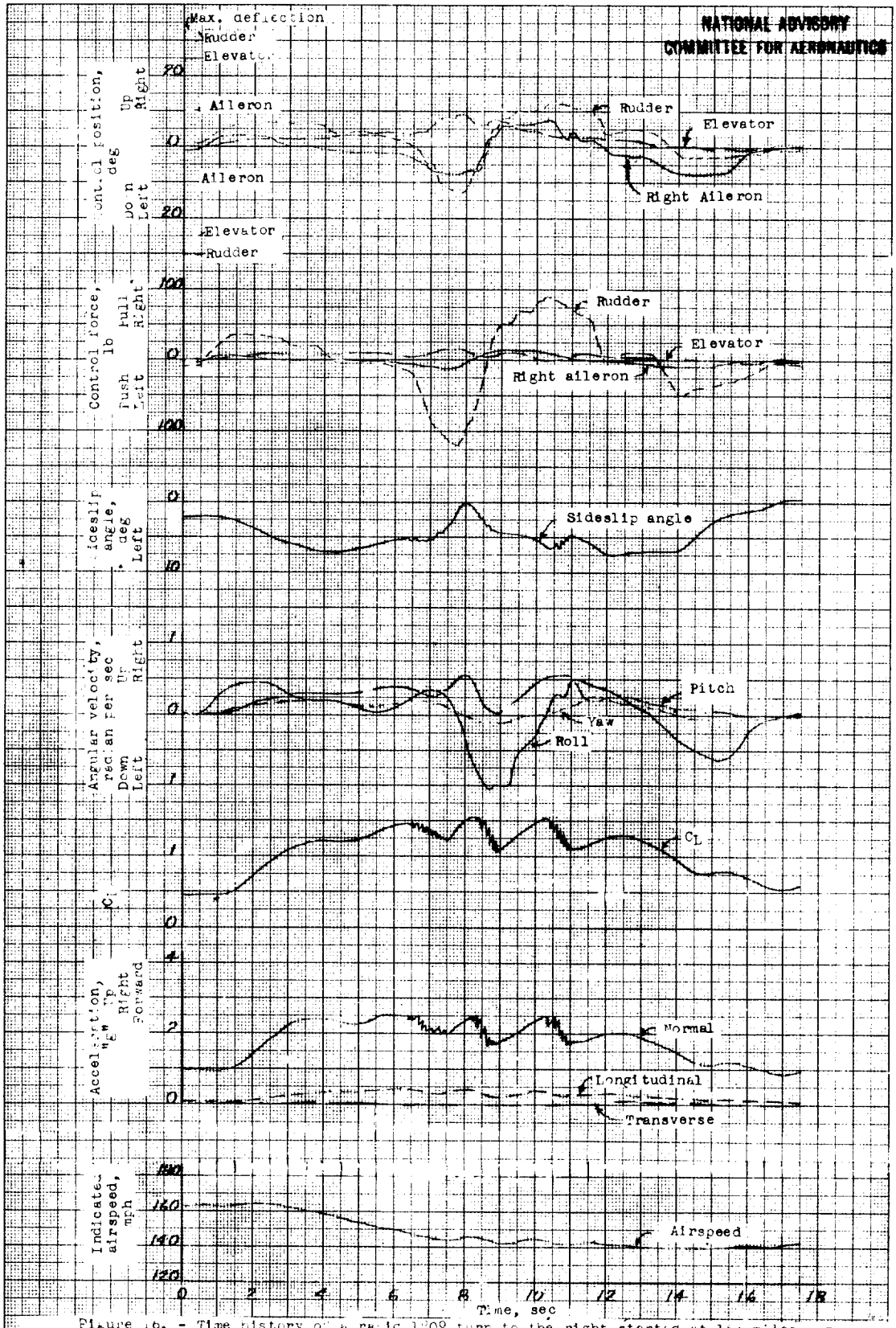

Figure 16. - Time history of a rapid 180° turn to the right started at 165 miles per hour, cruising condition. Center of gravity at 28.4 percent M.A.C. Gun ports covered. Model airplane.

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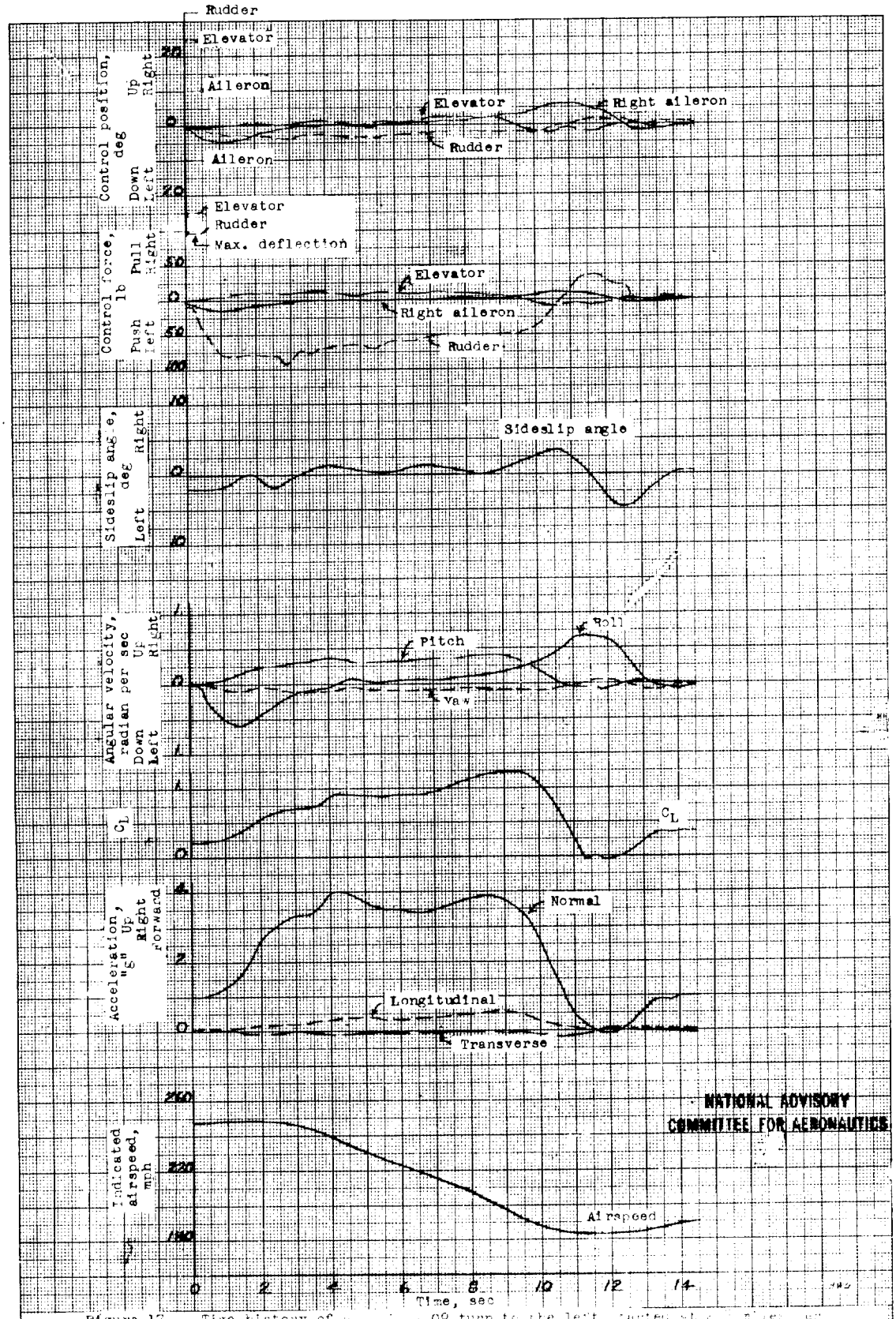

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Figure 17. - Time history of a [illegible] 90° turn to the left [illegible] hour, cruising condition. Center of gravity at [illegible] percent M.A.C. Gun ports covered. [illegible]-yl airplane.

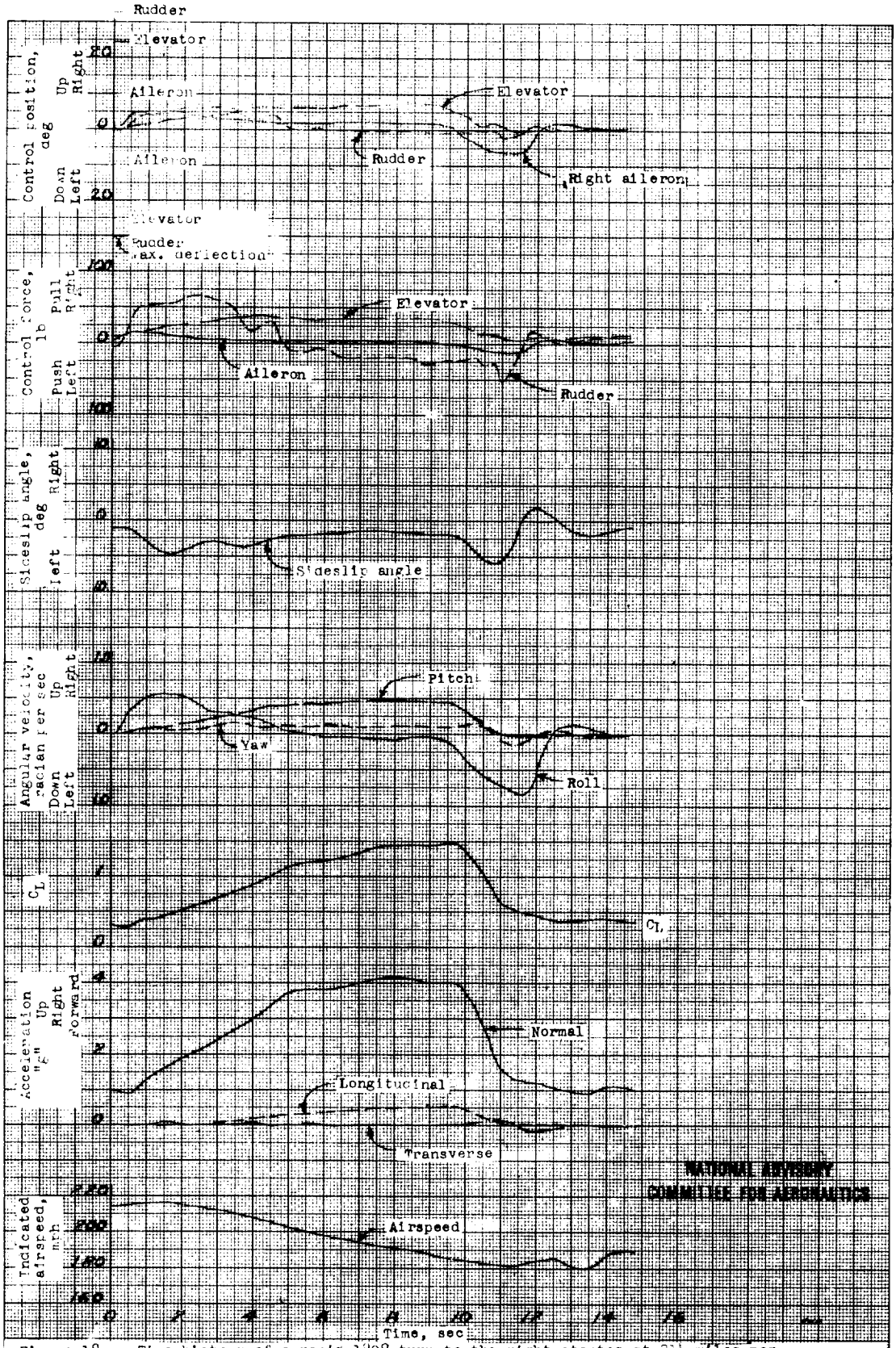

Figure 18. - Time history of a rapid 180° turn to the right started at 214 miles per hour combat condition. Center of gravity at 25.3 percent M.A.C. Gun ports covered. XP-51 airplane.

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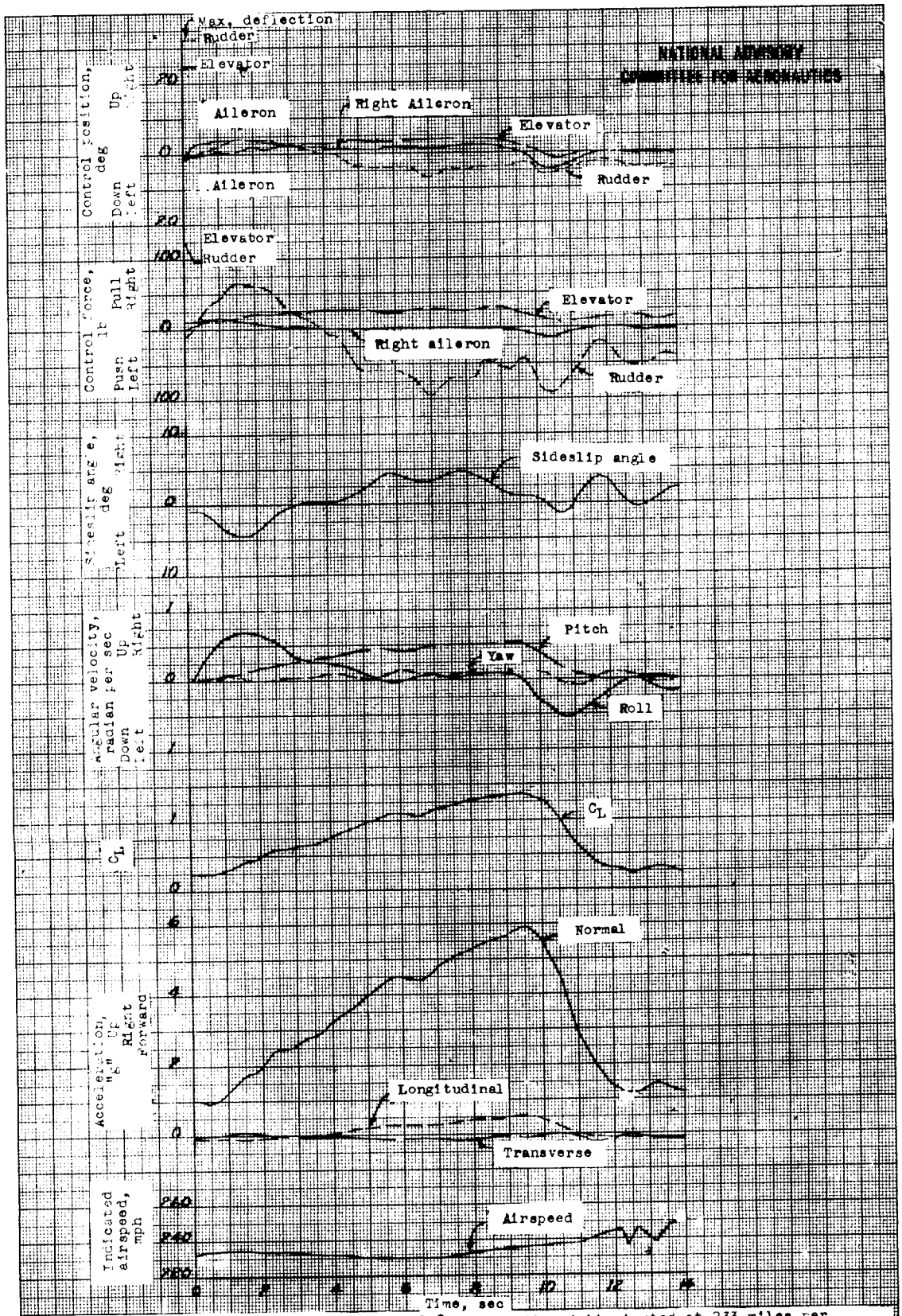

Figure 19. - Time history of a rapid 180° turn to the right started at 233 miles per hour, combat condition. Center of gravity at 28.3 percent M.A.C. Gun ports covered. XP-51 airplane.

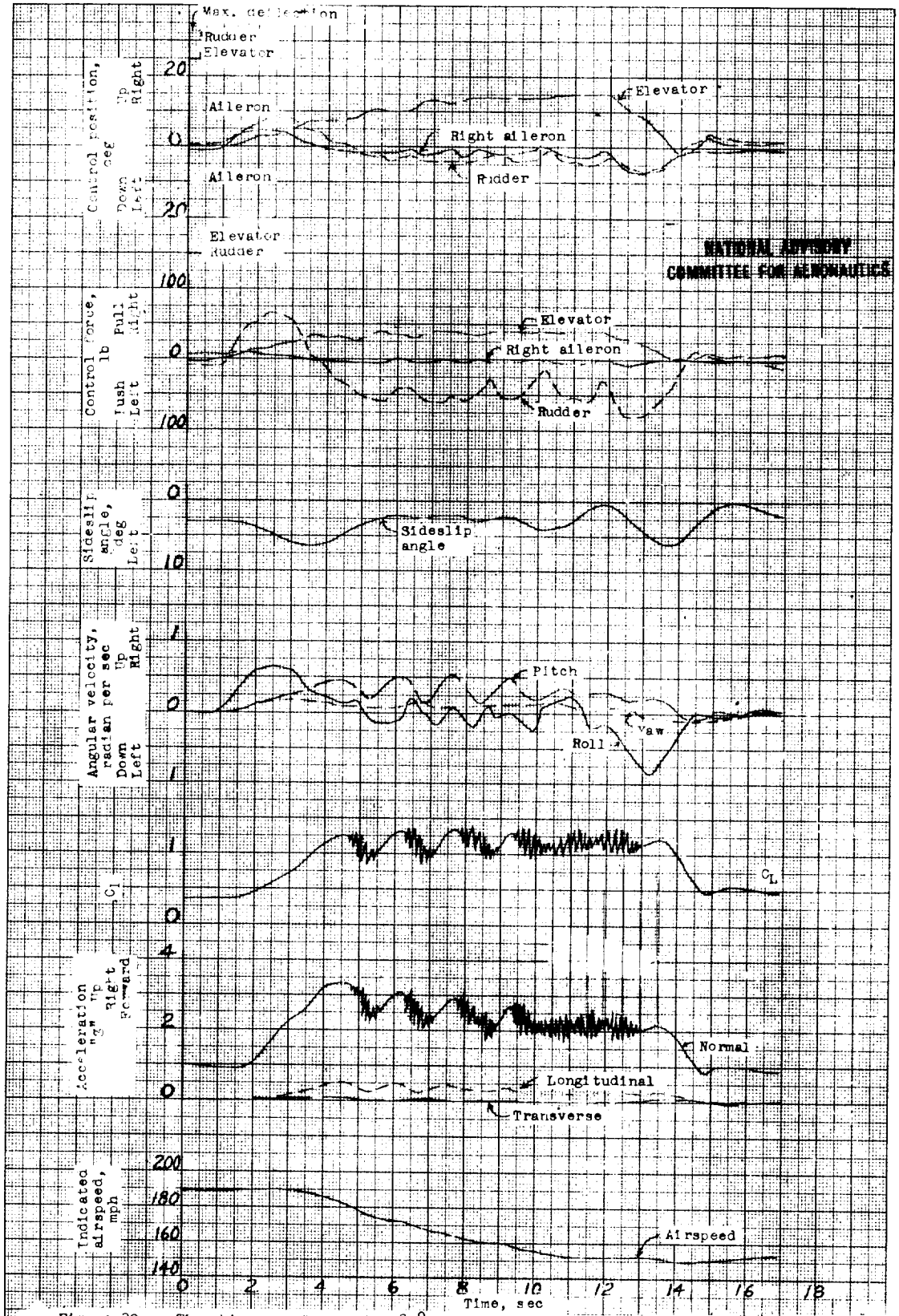

Figure 20. - Time history of a rapid 180° turn to the right started at 179 miles per hour. Cruising condition. Center of gravity at 24.5 percent M.A.C. Wing gun ports open, fuselage gun ports covered. XP-51 airplane.

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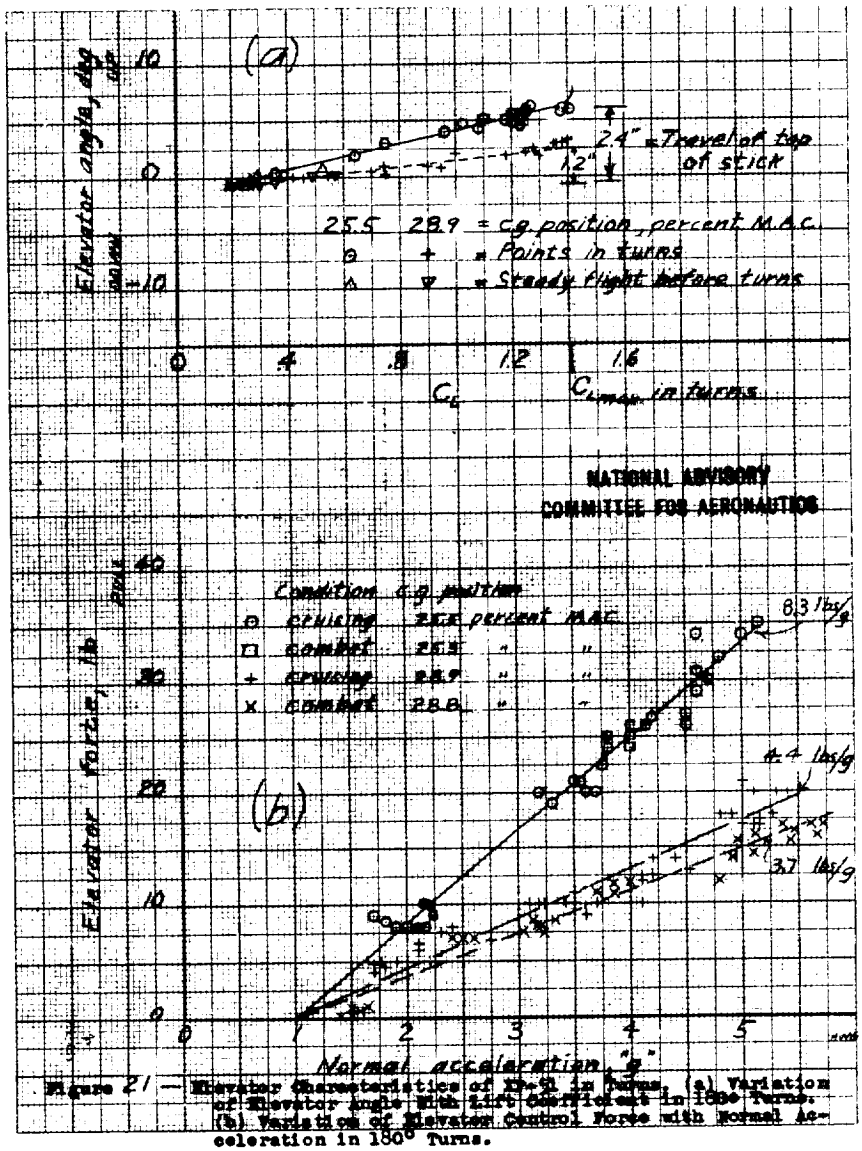

Figure 21 — Elevator Characteristics of XF-5 in Turns. (a) Variation of Elevator Angle with Lift Coefficient in 180° Turns. (b) Variation of Elevator Control Force with Normal Acceleration in 180° Turns.

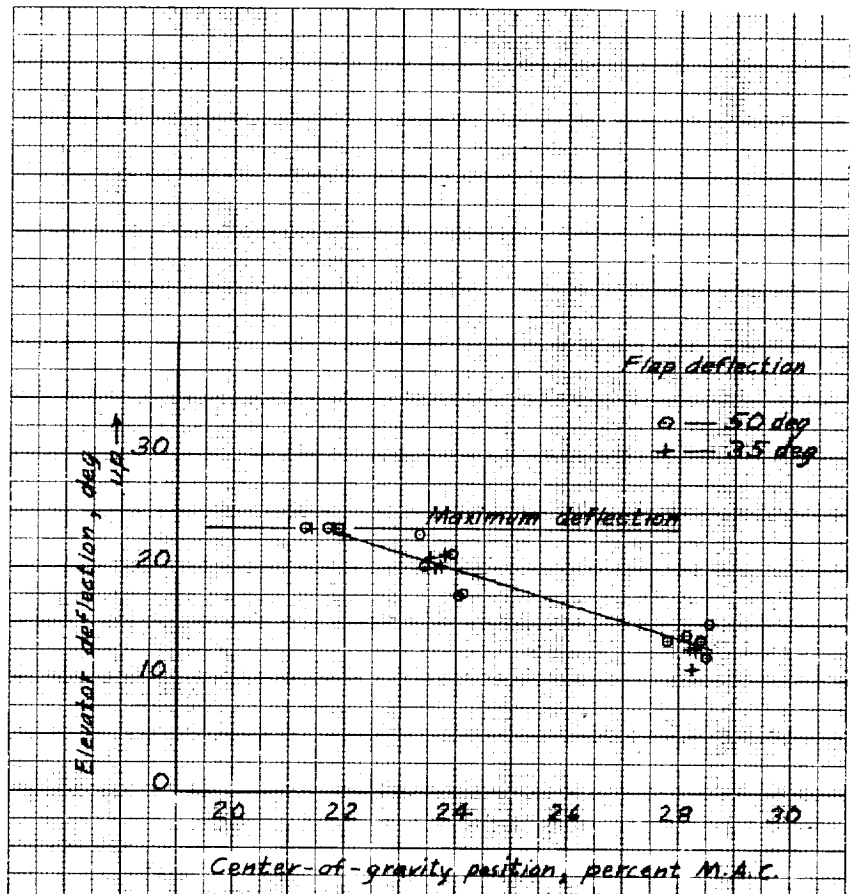

Figure 22 - Elevator Deflections Required to Make Three-Point Landings at Various Center-of-Gravity Positions. XB-51 Airplane.

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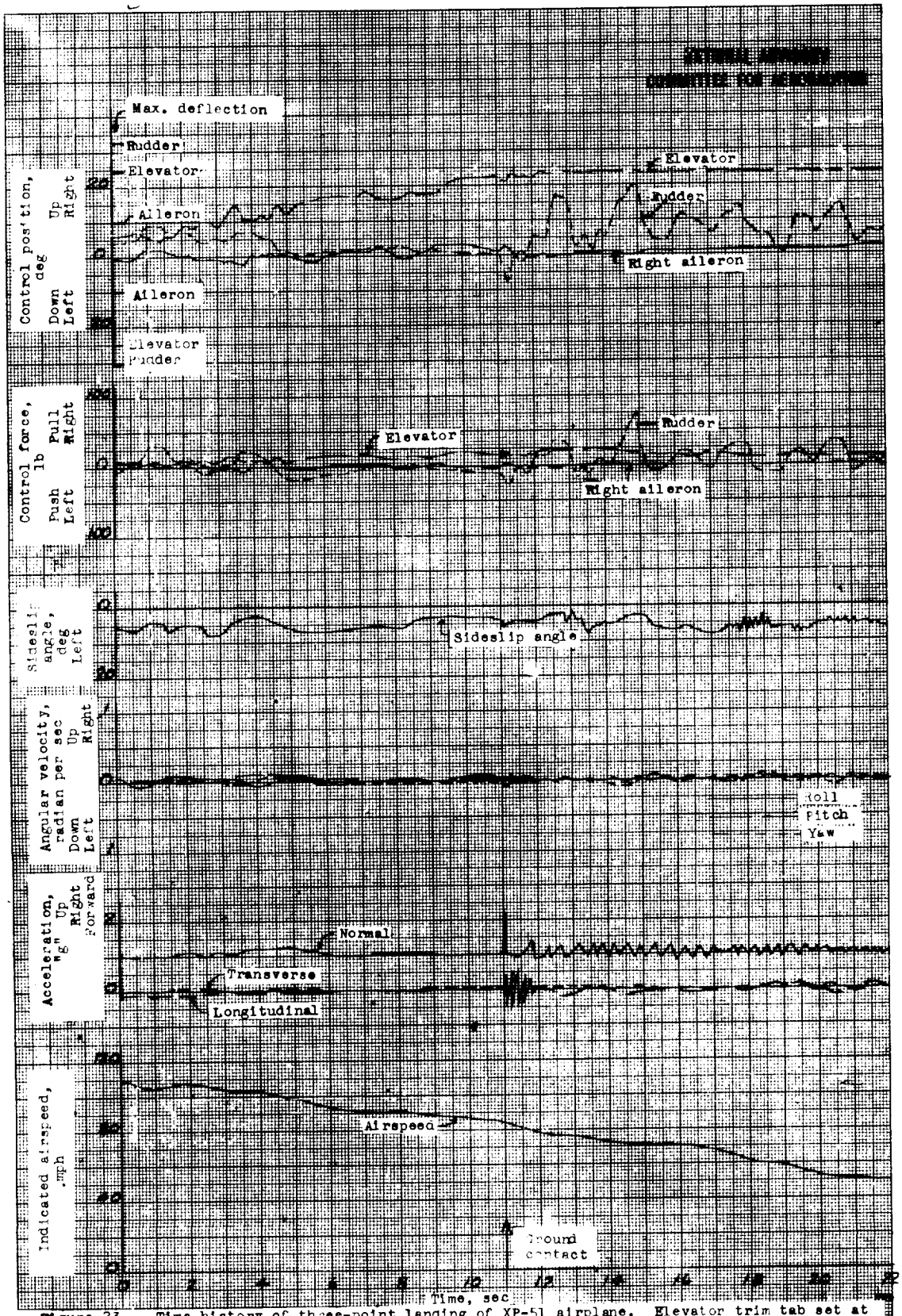

Figure 23. - Time history of three-point landing of XP-51 airplane. Elevator trim tab set at + 10°. Contact made at 84 miles per hour with elevator 22° up. Center of gravity at 24.0 percent M.A.C.

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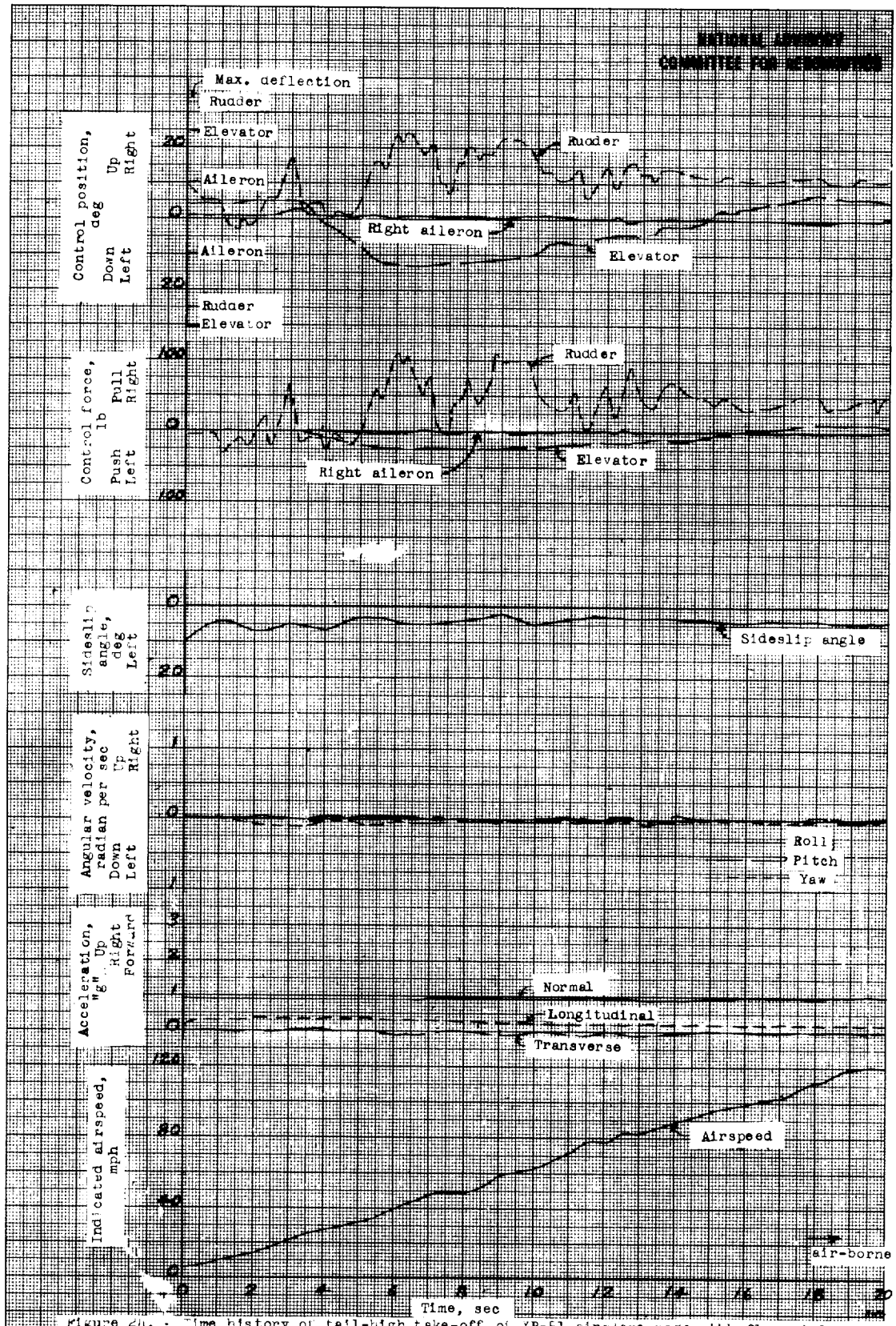

Figure 24. - Time history of tail-high take-off of XP-51 airplane made with flaps deflected 20°; 45 inches of mercury manifold pressure; 2800 rpm; and not air-borne until reaching 110 miles per hour. Center of gravity at 25.5 percent M.A.C.

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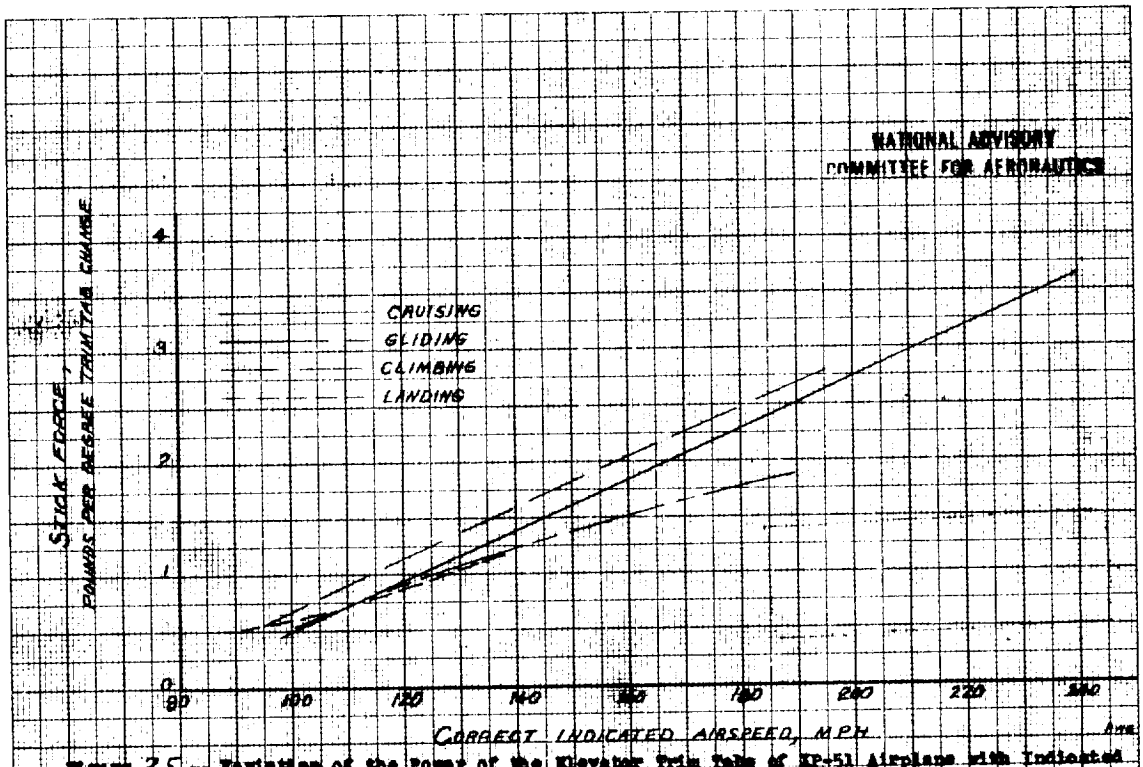

Figure 25 — Variation of the Power of the Elevator Trim Tabs of XP-51 Airplane with Indicated Airspeed in Cruising, Gliding, Climbing and Landing Conditions.

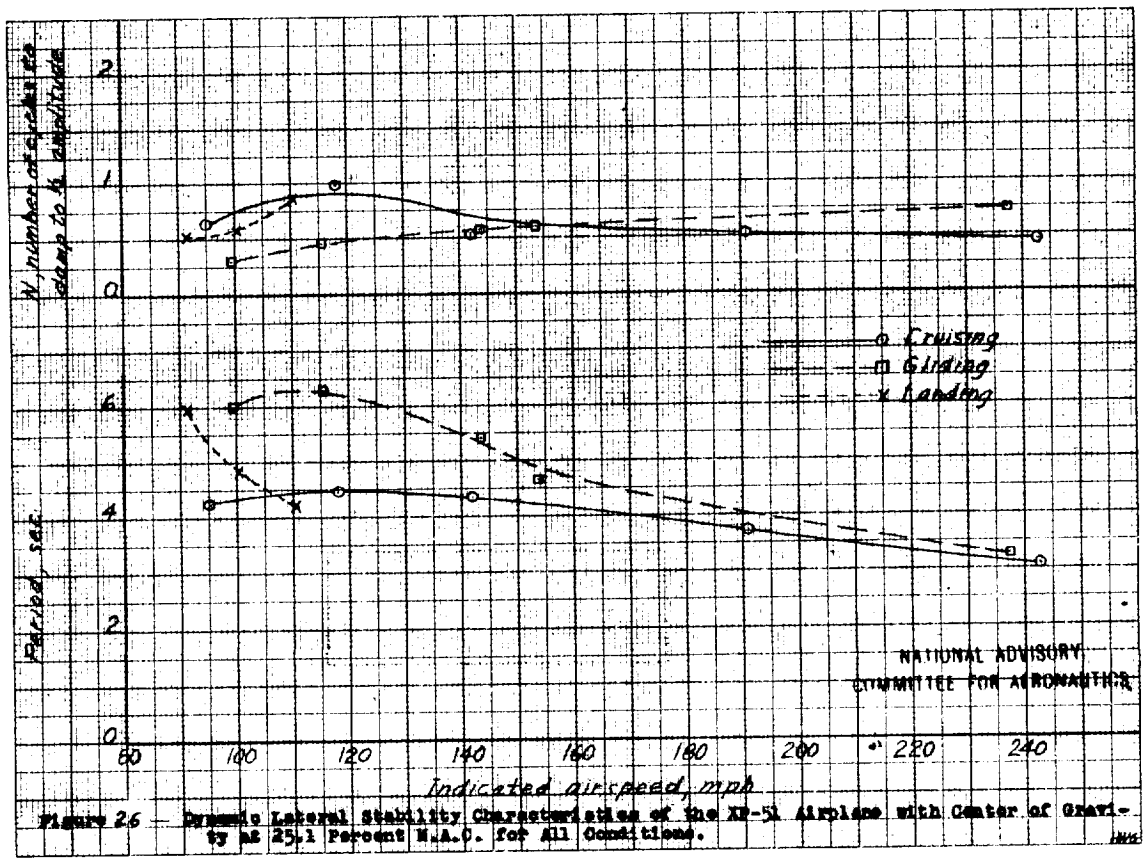

Figure 26 — Dynamic Lateral Stability Characteristics of the XP-51 Airplane with Center of Gravity at 25.1 Percent M.A.C. for All Conditions.

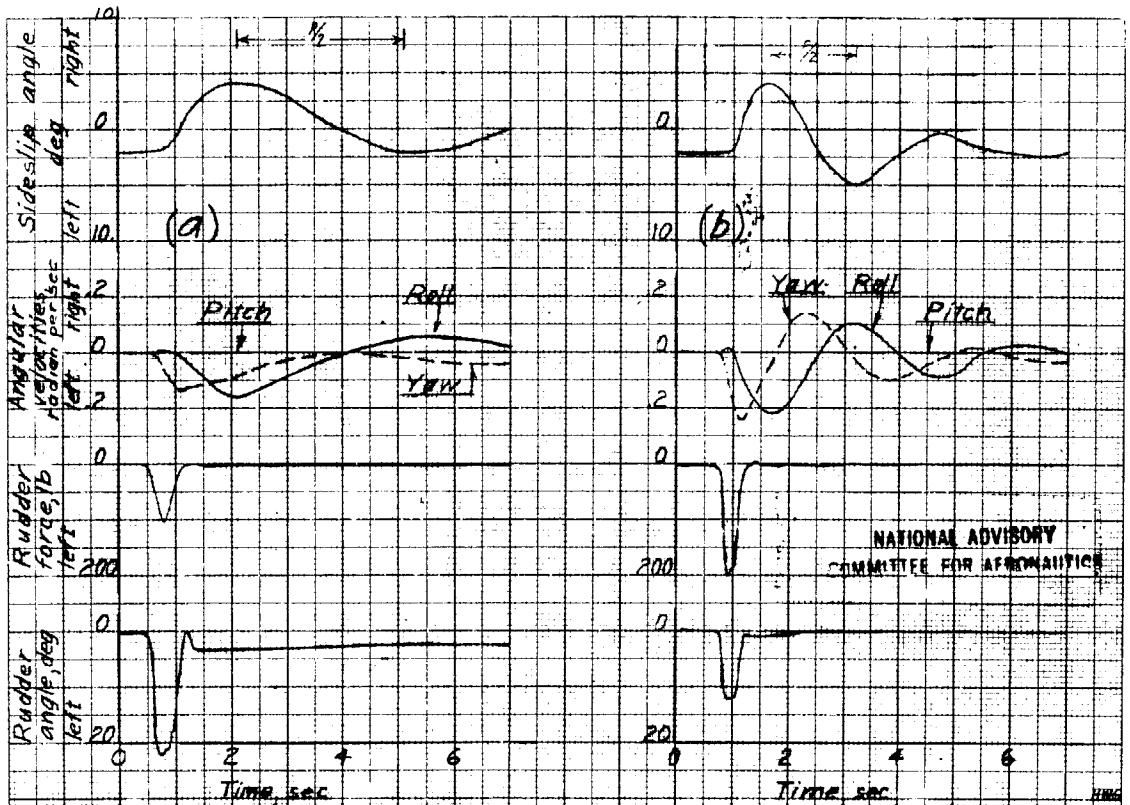

Figure 27 - Time Histories of Typical [redacted] Lateral Oscillations of the XP-5[redacted] Airplane Started by Abruptly Deflecting the Rudder and Releasing All Controls in (a) Gliding Conditions at 1[redacted] Miles per Hour, Center of Gravity at 25.5 Percent M.A.C. and (b) Cruising Condition at 243 Miles Per Hour, Center of Gravity at 25.2 Percent M.A.C.

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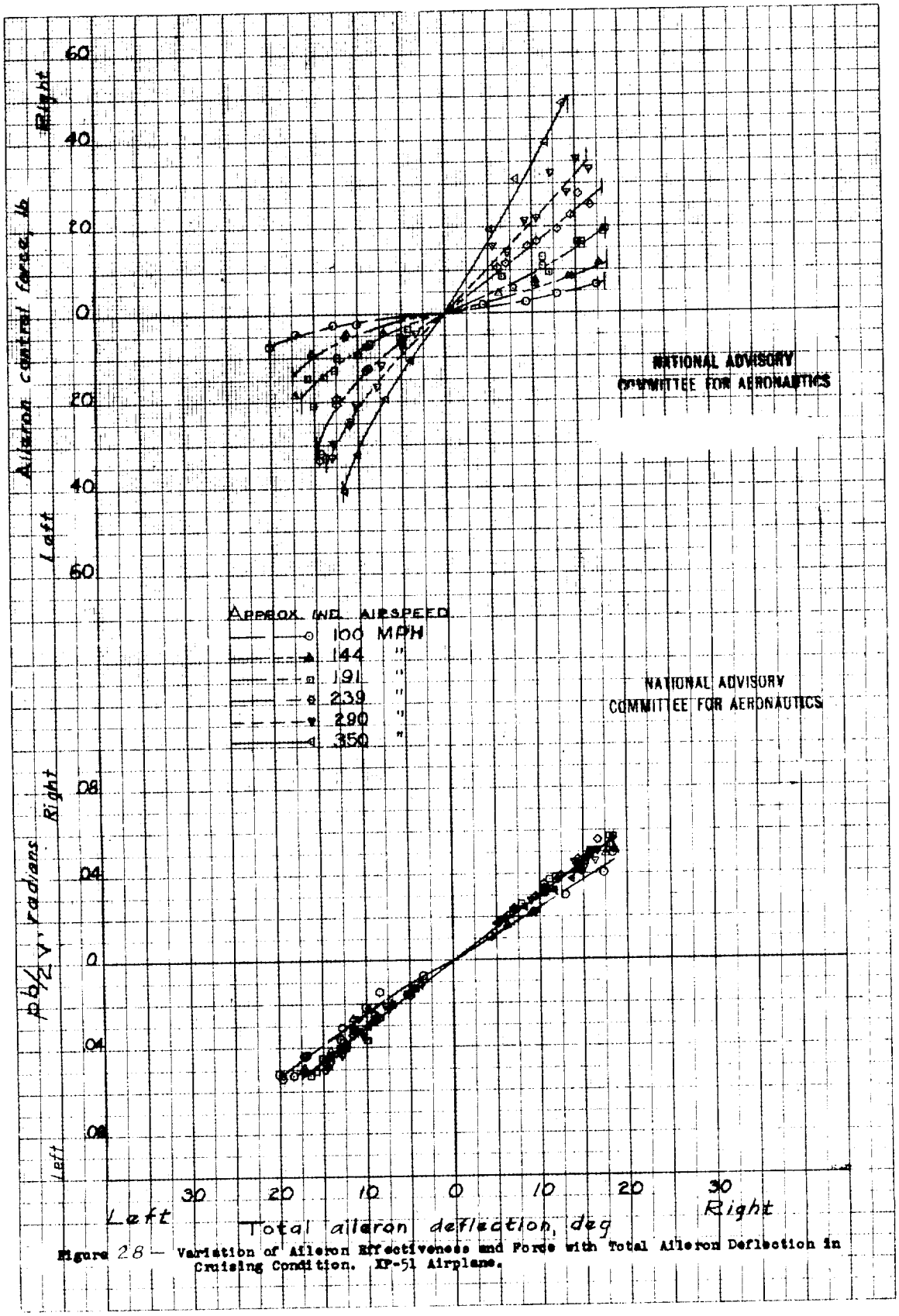

Figure 28 — Variation of Aileron Effectiveness and Force with Total Aileron Deflection in Cruising Condition. XP-51 Airplane.

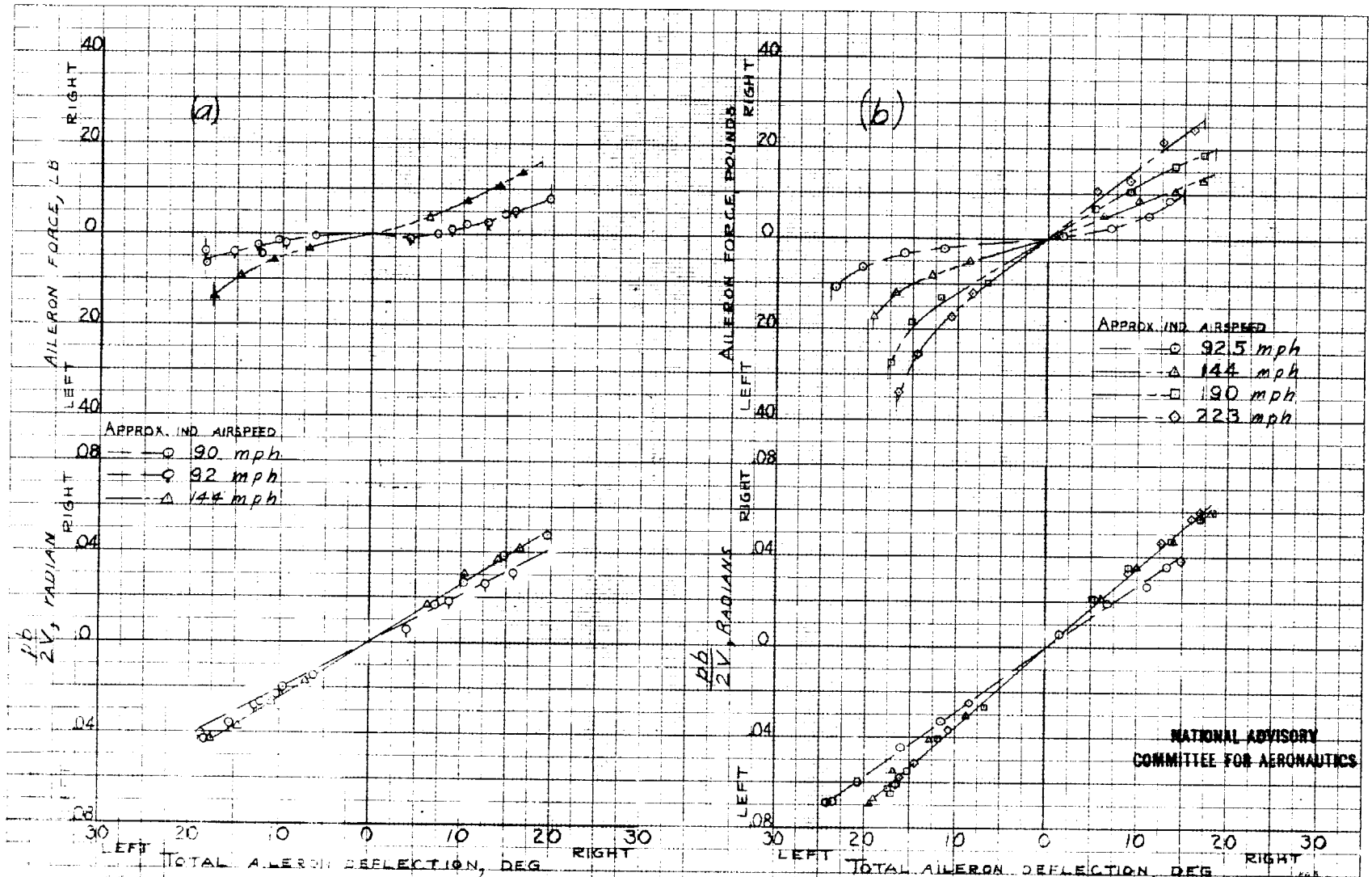

Figure [illegible] — Variation of Aileron Effectiveness and Force with Total Aileron Deflection in (a) Landing Condition, and (b) Combat Condition, Flaps Deflected 20°. XP-51 Airplane.

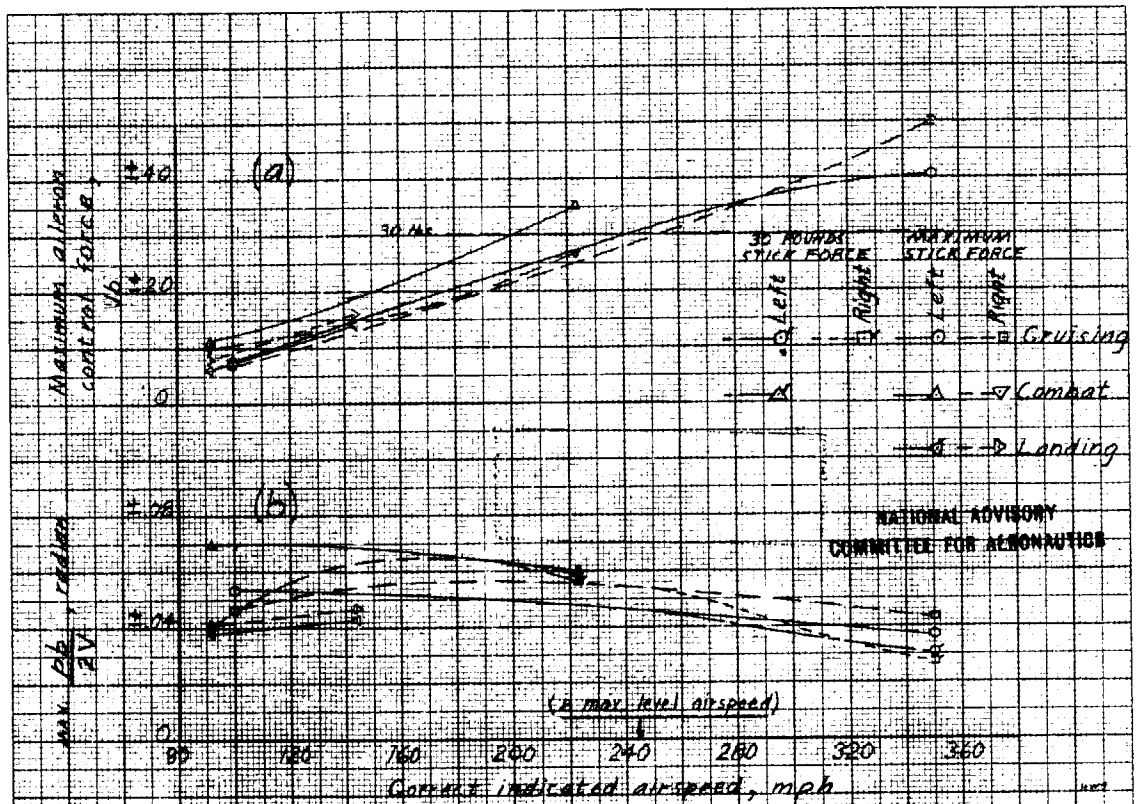

Figure 30 — Variation of (a) Maximum Aileron Control Force and (b) Maximum Aileron Effectiveness of XP-51 Airplane with Corrected Indicated Airspeed in Cruising, Combat, and Landing Conditions.

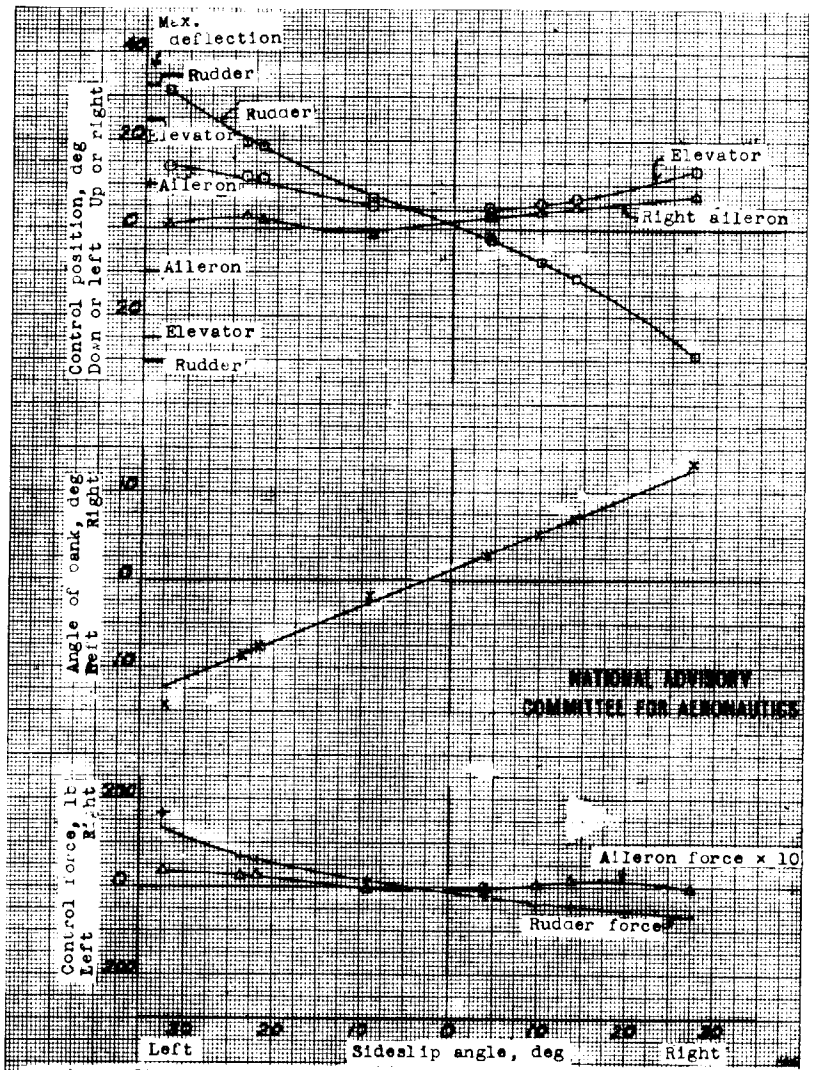

Figure 31. - Steady sideslip characteristics of XP-51 airplane in cruising condition at about 110 miles per hour with center of gravity at 25.5 percent M.A.C.

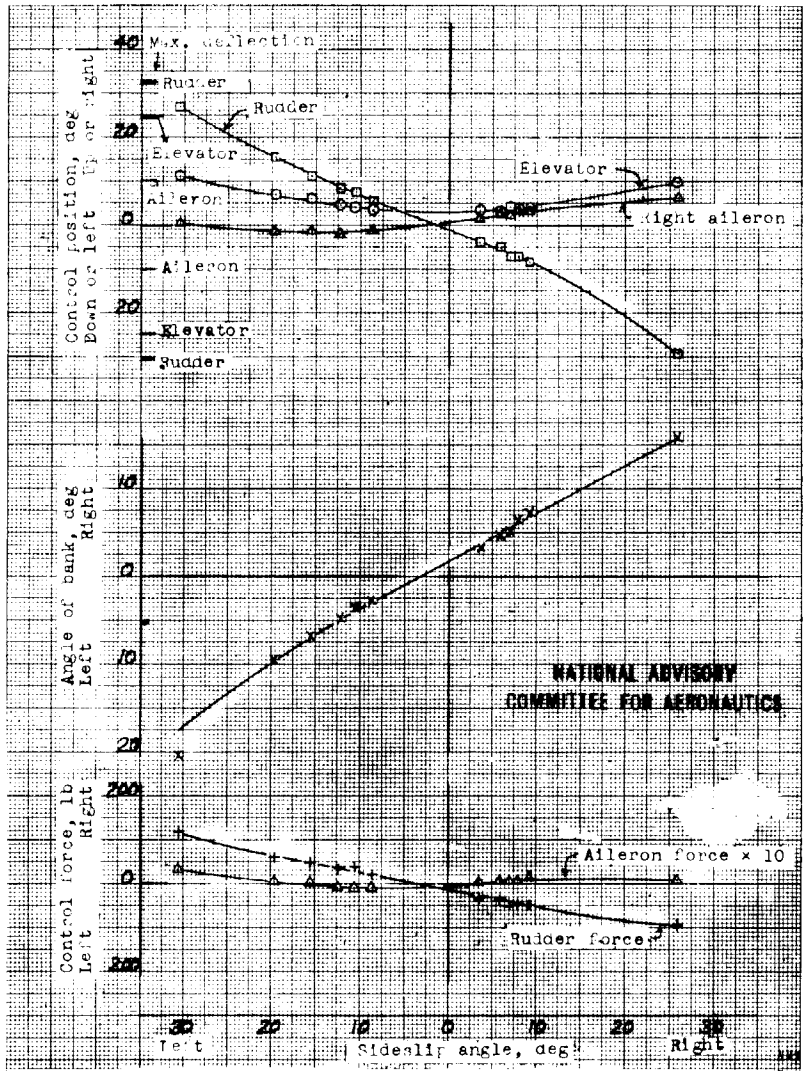

Figure 32. - Steady sideslip characteristics of XP-51 airplane in cruising condition at about 153 miles per hour with center of gravity at 25.2 percent M.A.C.

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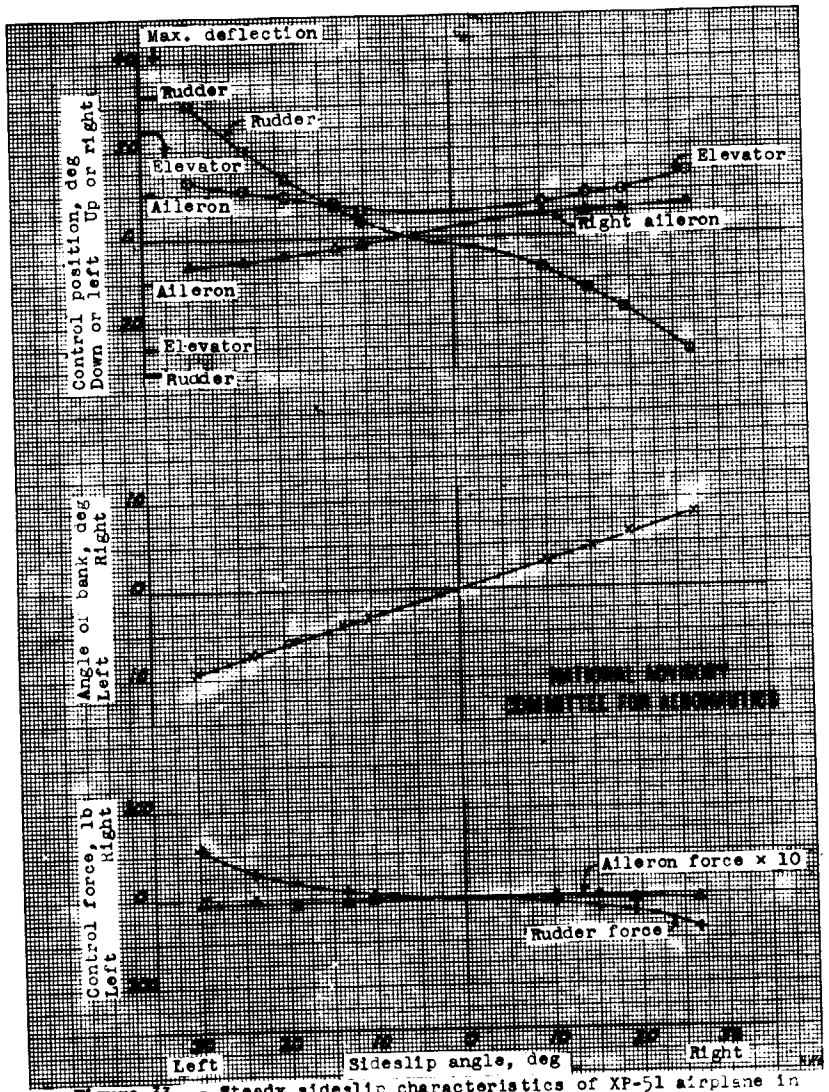

Figure 33. - Steady sideslip characteristics of XP-51 airplane in gliding condition at 112 miles per hour with center of gravity at 24.9 percent M.A.C.

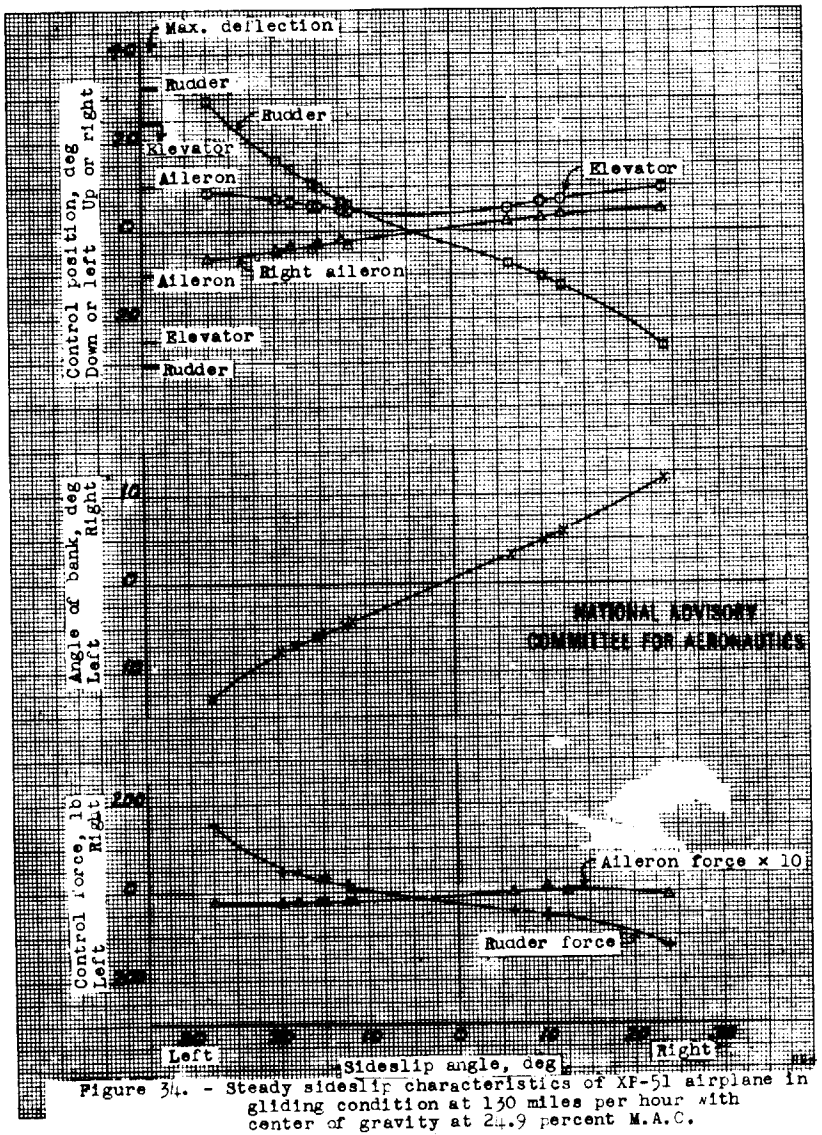

Figure 34. - Steady sideslip characteristics of XP-51 airplane in gliding condition at 130 miles per hour with center of gravity at 24.9 percent M.A.C.

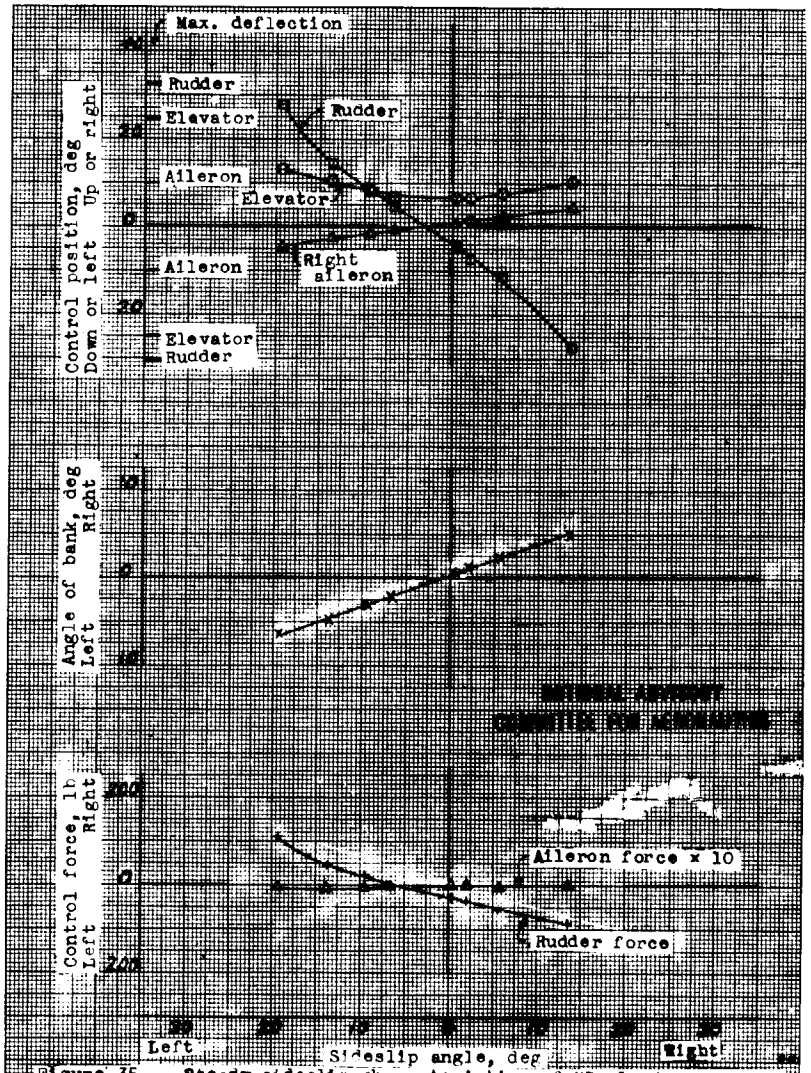

Figure 35. - Steady sideslip characteristics of XP-51 airplane in landing condition at 108 miles per hour with center of gravity at 25.1 percent M.A.C.

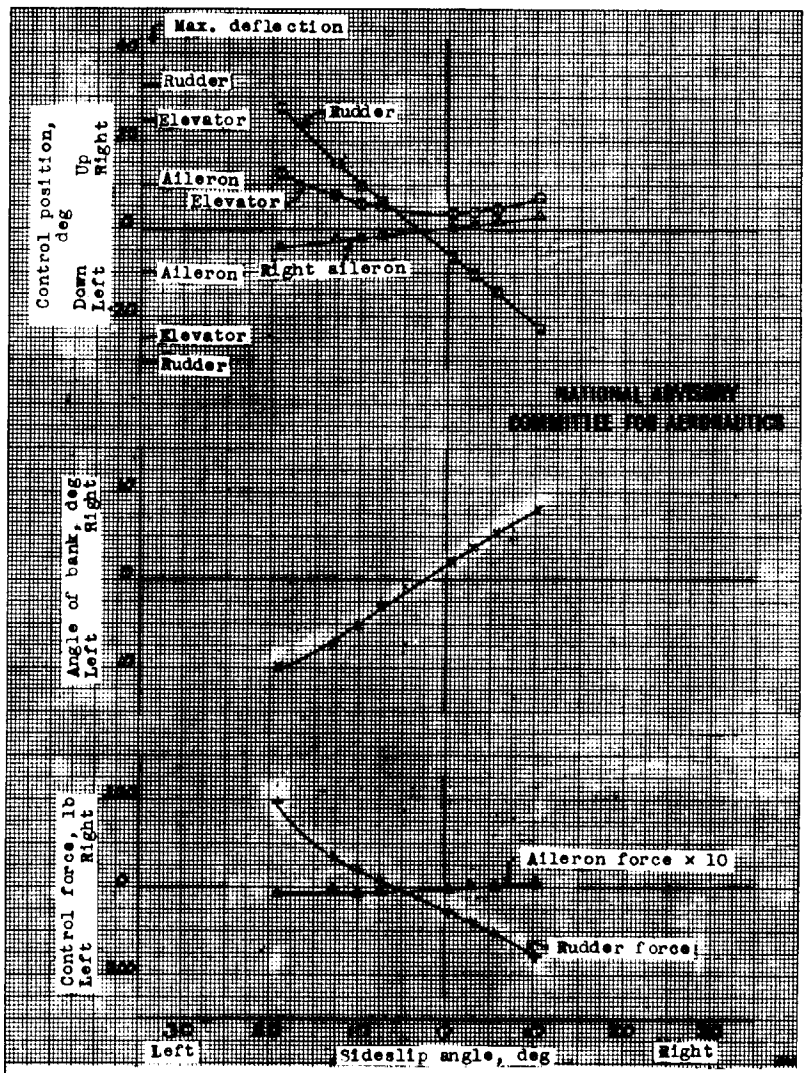

Figure 36. - Steady sideslip characteristics of XP-51 airplane in landing condition at 136 miles per hour with center of gravity at 24.9 percent M.A.C.

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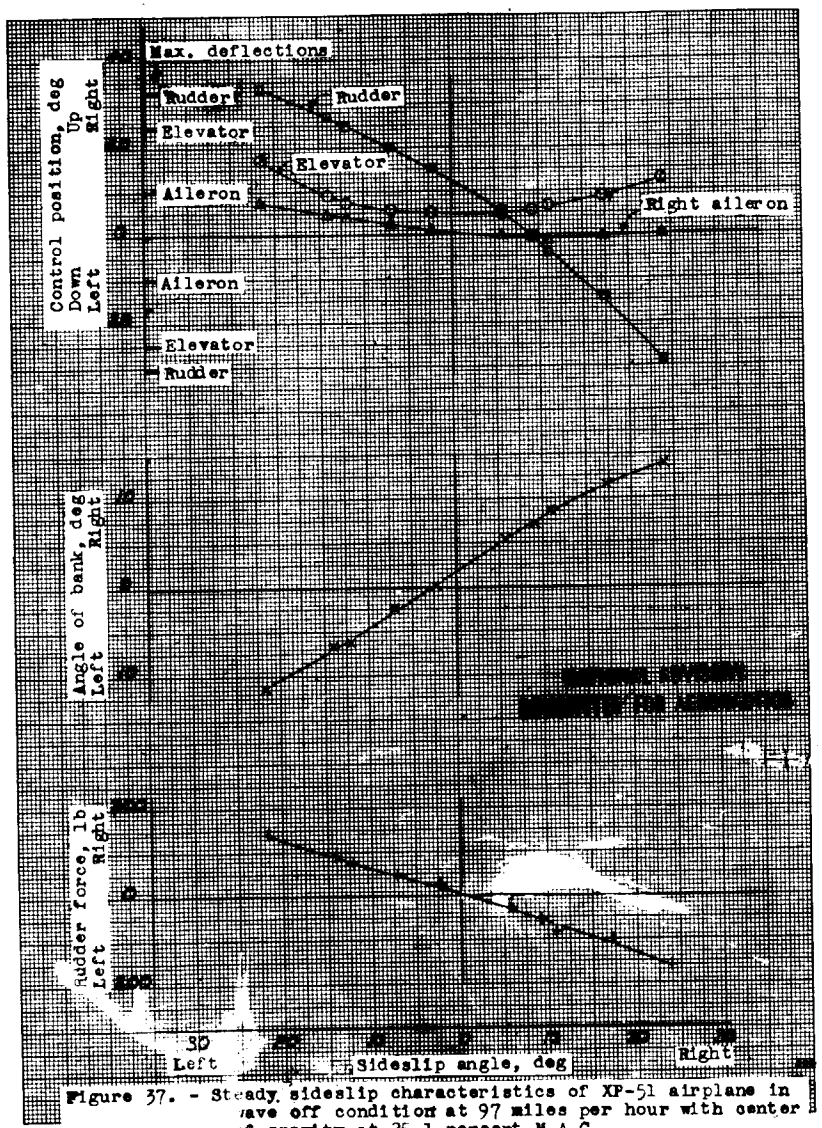

Figure 37. - Steady sideslip characteristics of XP-51 airplane in wave off condition at 97 miles per hour with center of gravity at 25.1 percent M.A.C.

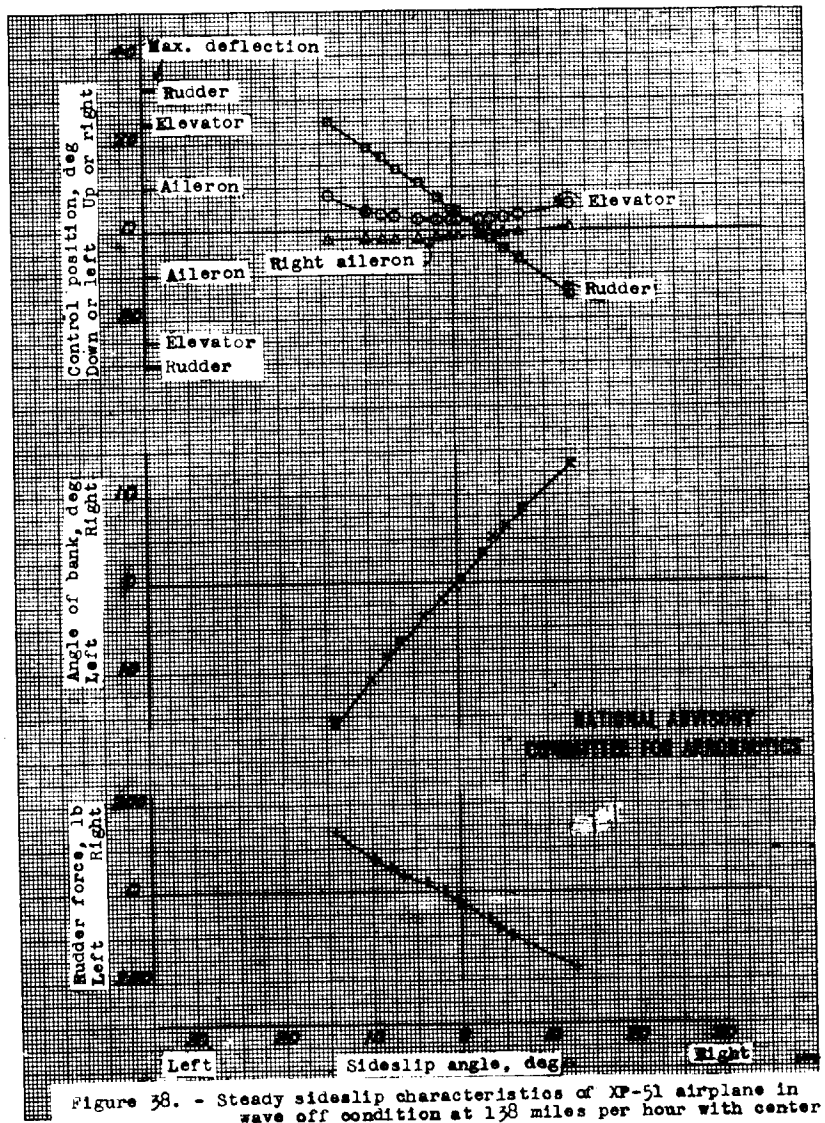

Figure 38. - Steady sideslip characteristics of XP-51 airplane in wave off condition at 138 miles per hour with center of gravity at 24.5 percent M.A.C.

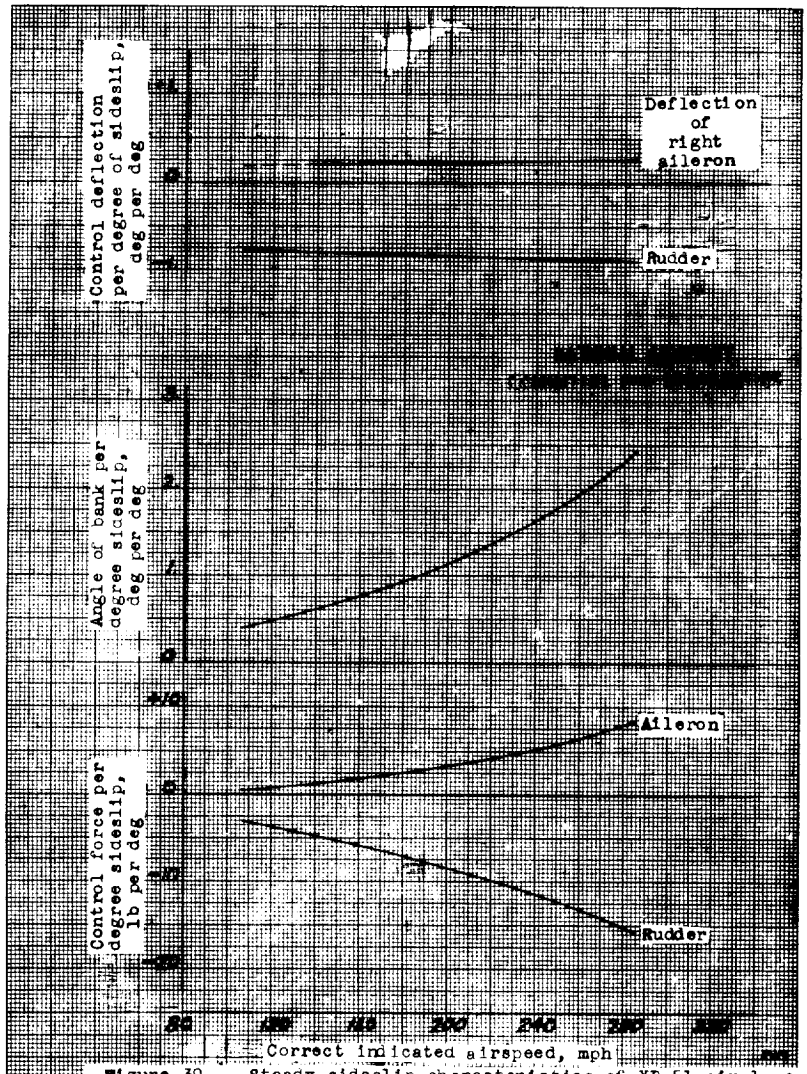

Figure 39. - Steady sideslip characteristics of XP-51 airplane for small rudder deflections at various airspeeds in cruising condition with center of gravity at 25.3 percent M.A.C.

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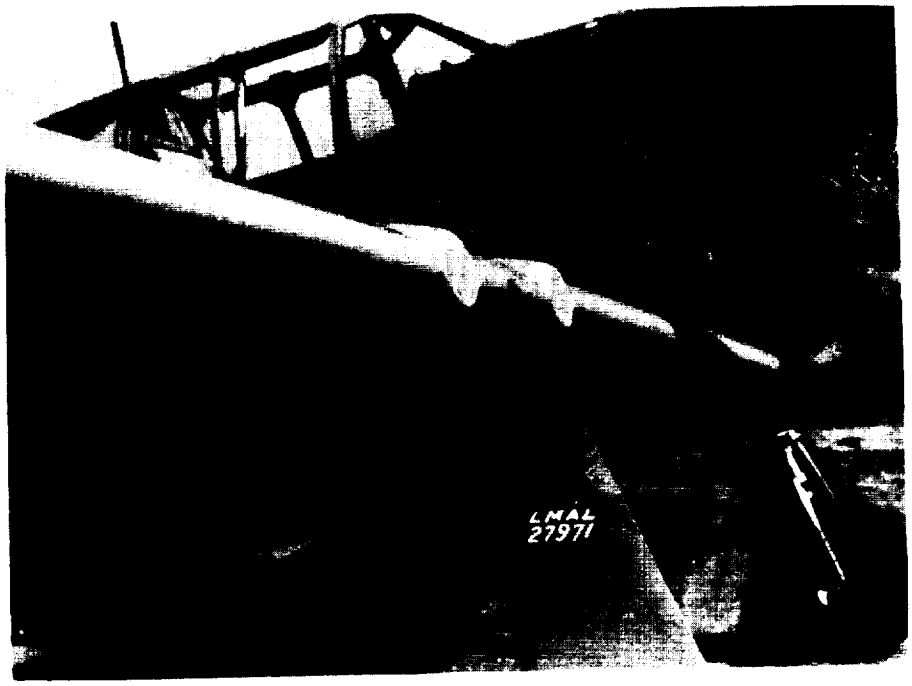

Figure 40.- Photograph of gun ports on leading edge of right wing of XP-51 airplane covered with doped fabric (clean wing).

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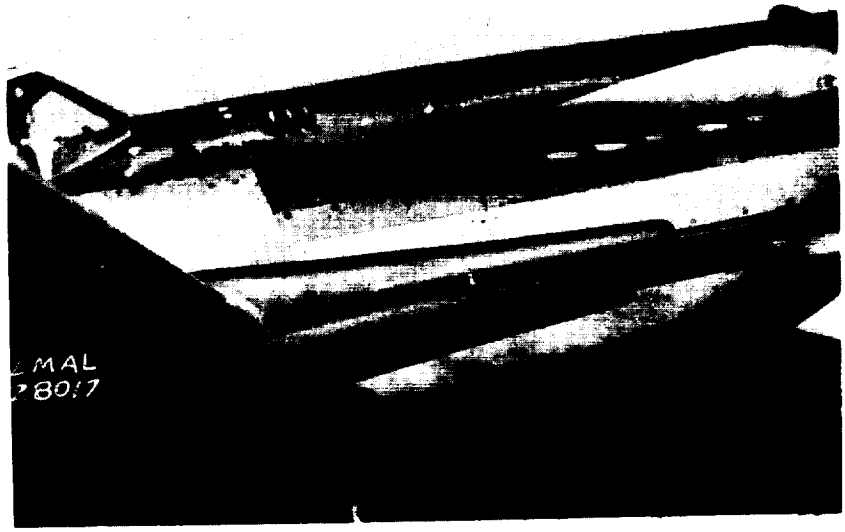

Figure 41(a).- Two 20-millimeter gun mock-ups installed on leading edge of right wing of XP-51 airplane.

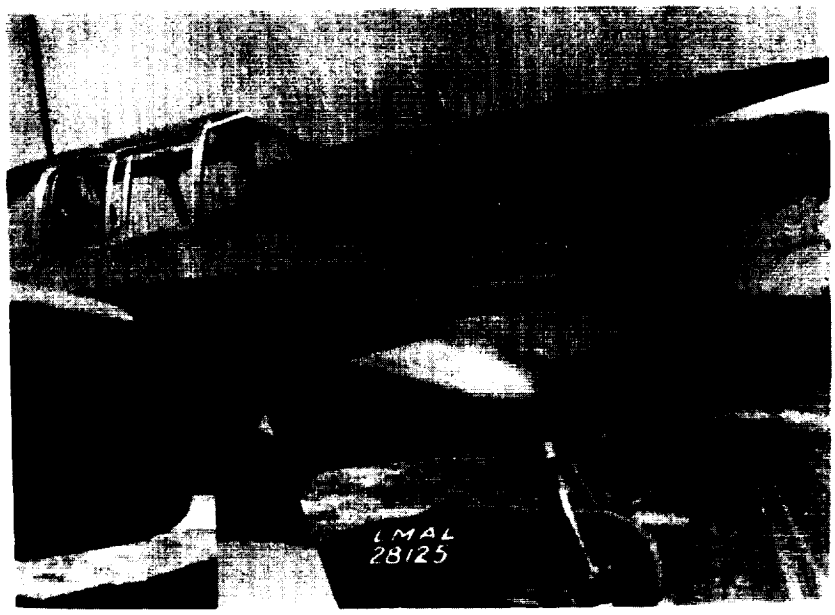

Figure 41(b).- Two modified 20-millimeter gun mockups installed on leading edge of right wing of XP-51 airplane.

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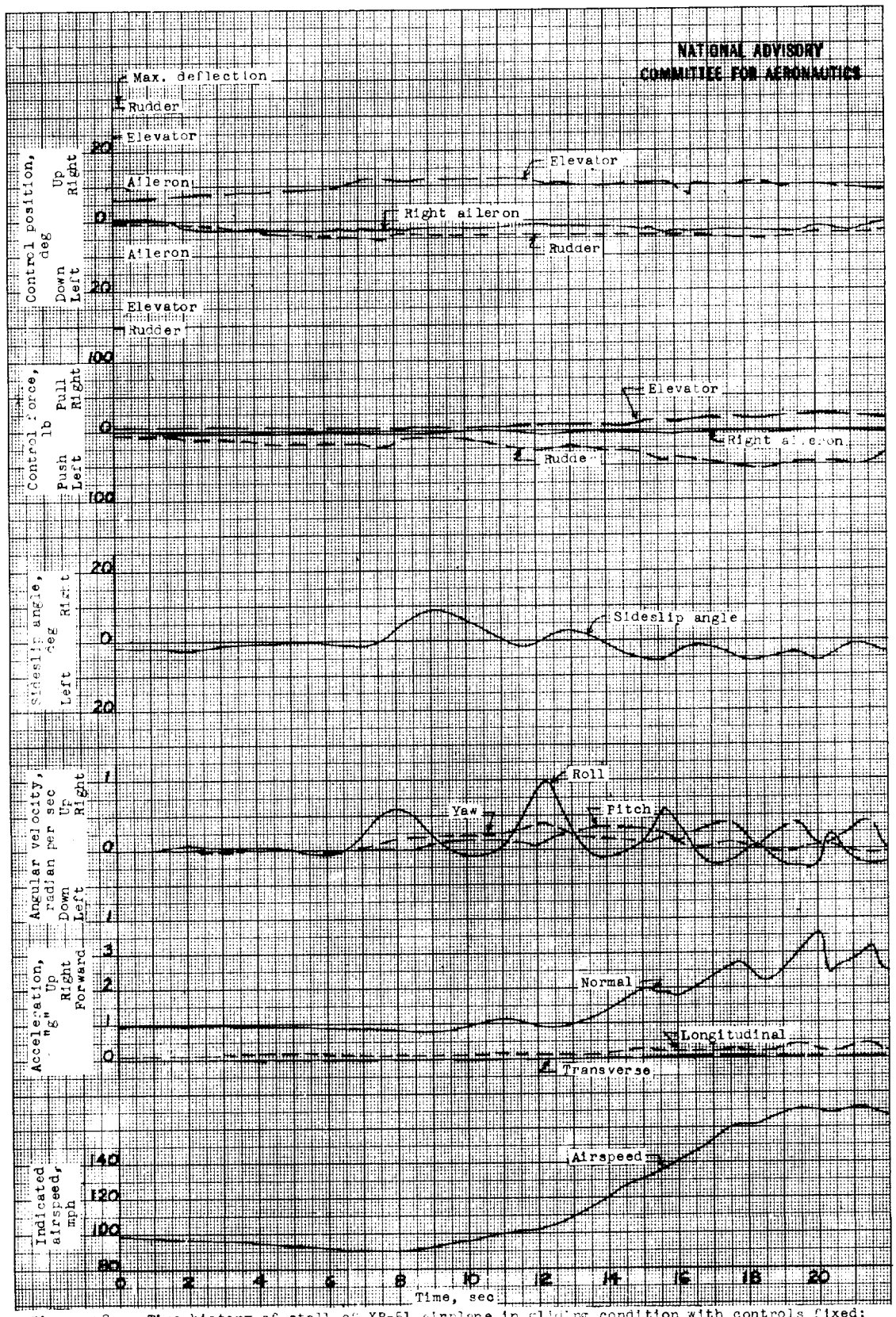

Figure 42. - Time history of stall of XP-51 airplane in gliding condition with controls fixed; center of gravity at 29.2 percent M.A.C.; clean wing.

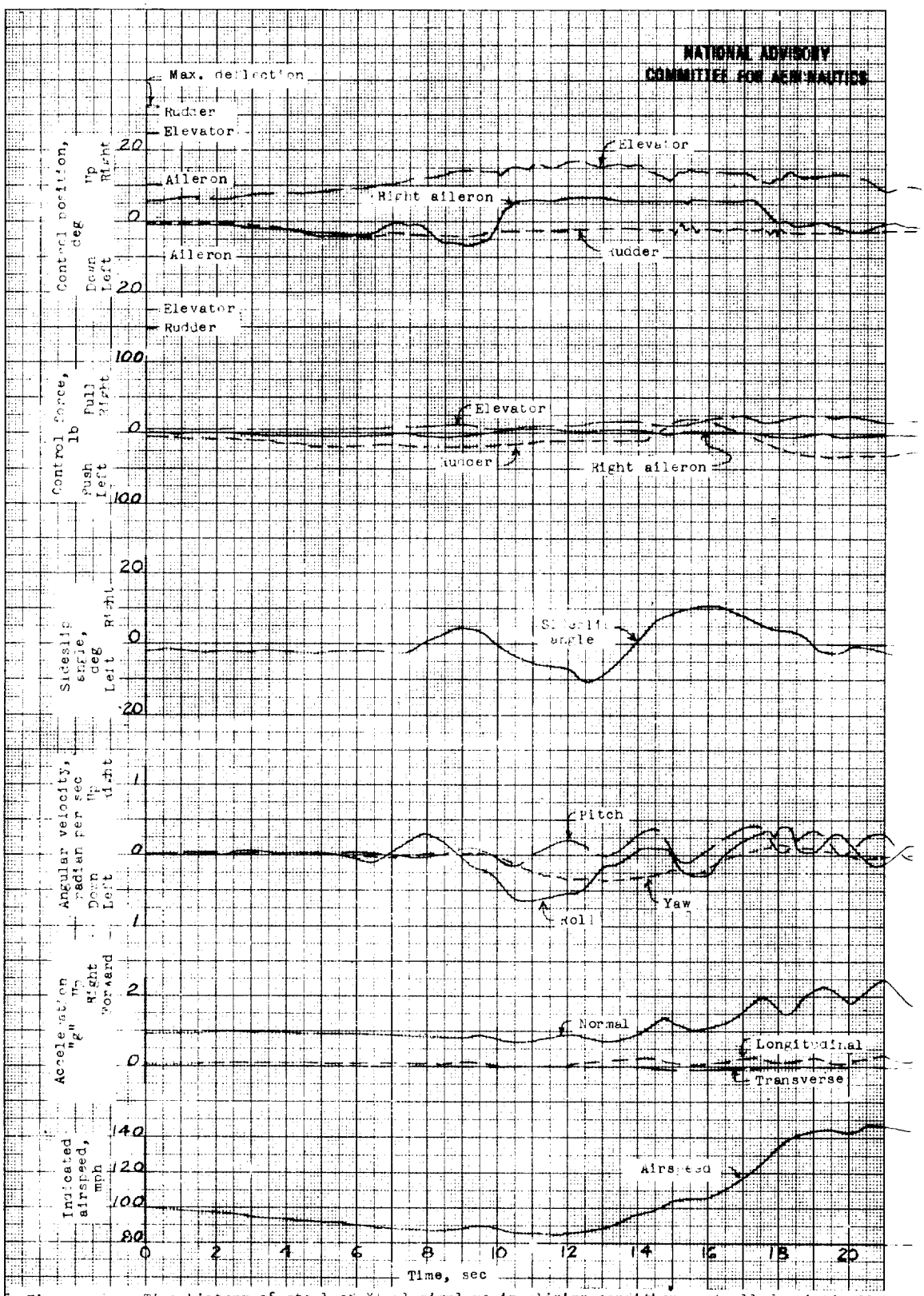

Figure 49. - Time history of stall of XF-91 airplane in gliding condition controlled principally by ailerons; center of gravity at 25.5 percent M.A.C.; clean wing.

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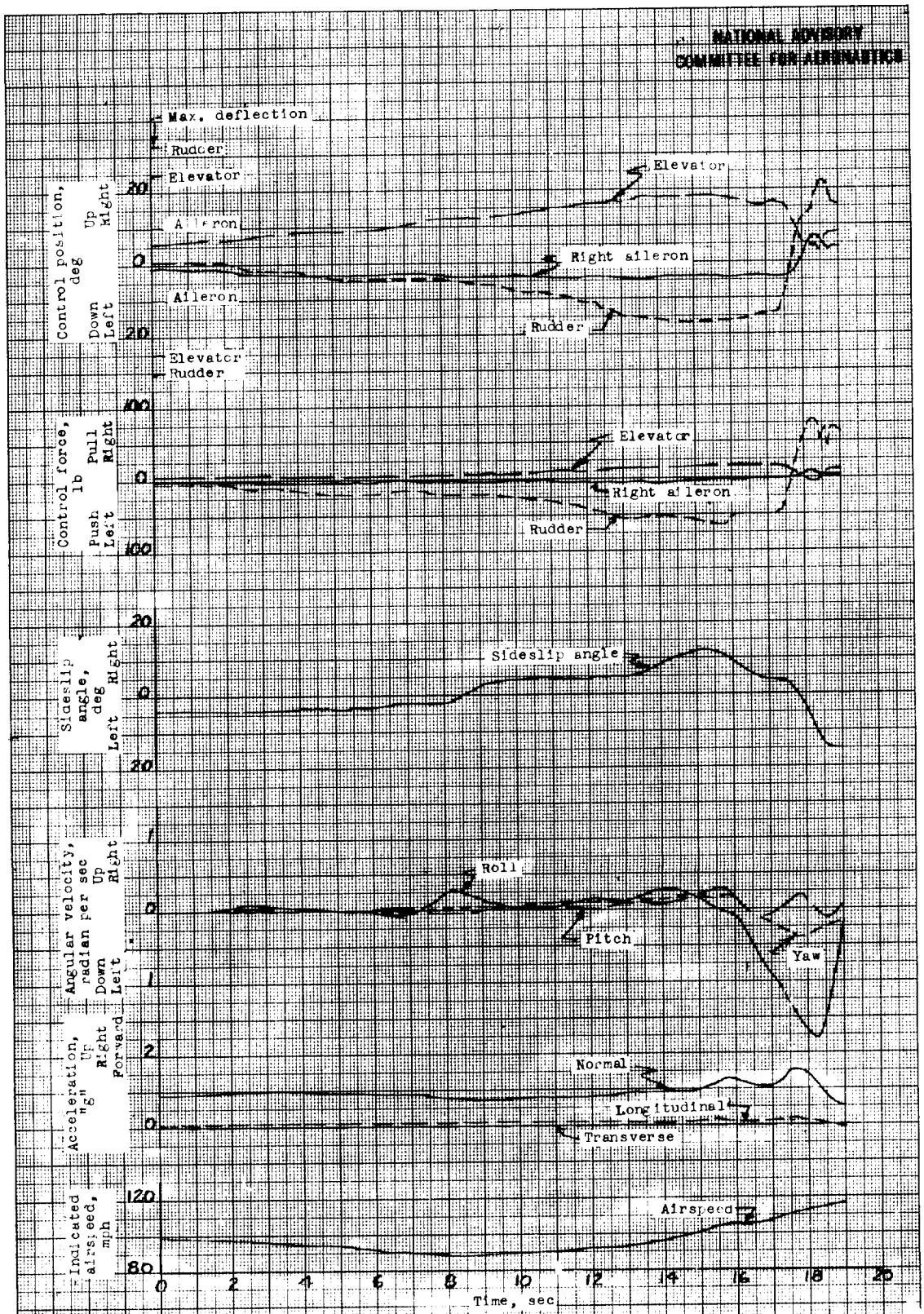

Figure 4. - Time history of stall of XP-51 airplane in gliding condition controlled principally by rudder; center of gravity at 25.4 percent M.A.C.; clean wing.

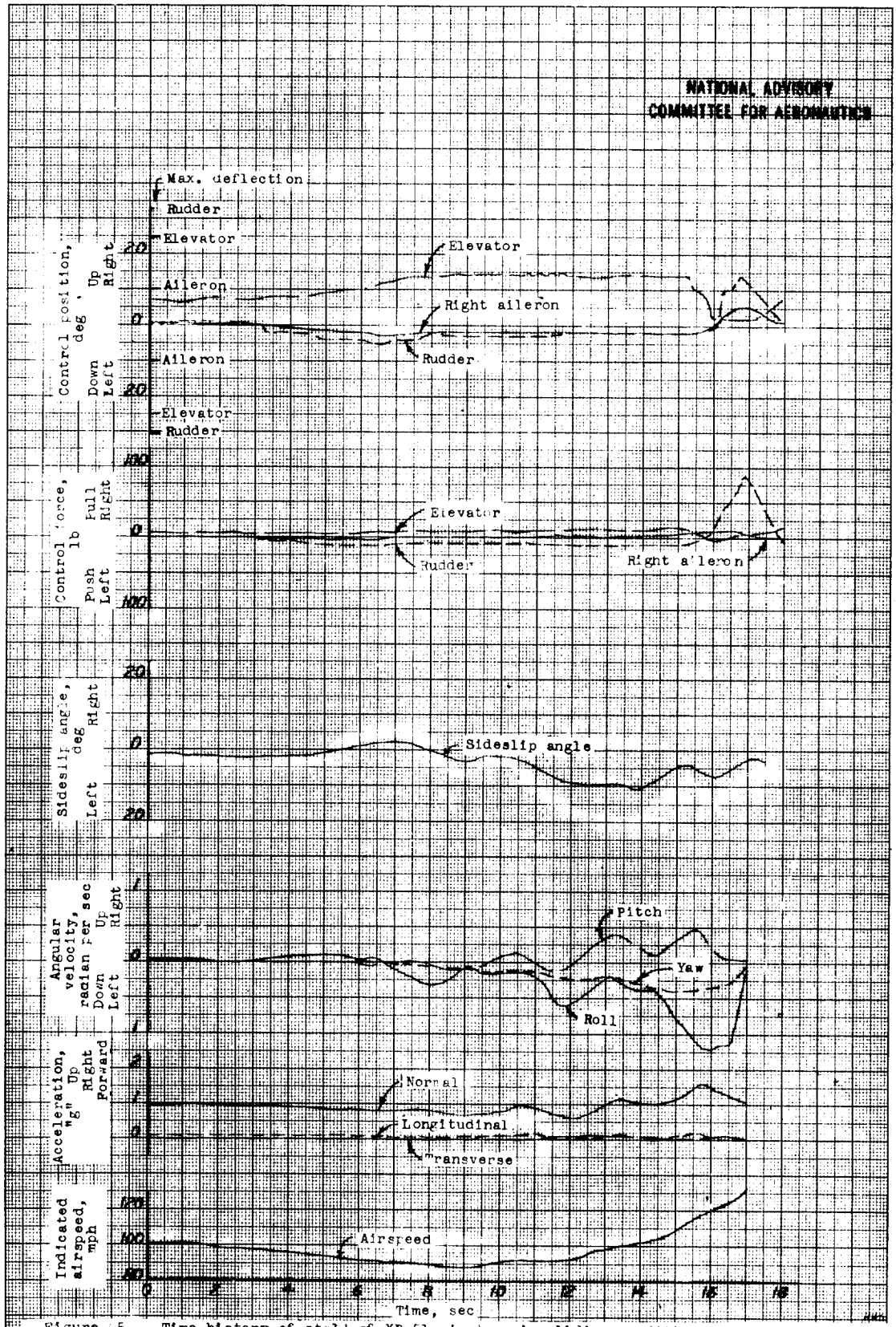

Figure 45. - Time history of stall of XP-51 airplane in gliding condition with controls fixed; center of gravity at 25.4 percent M.A.C.; four 20-millimeter gun mockups.

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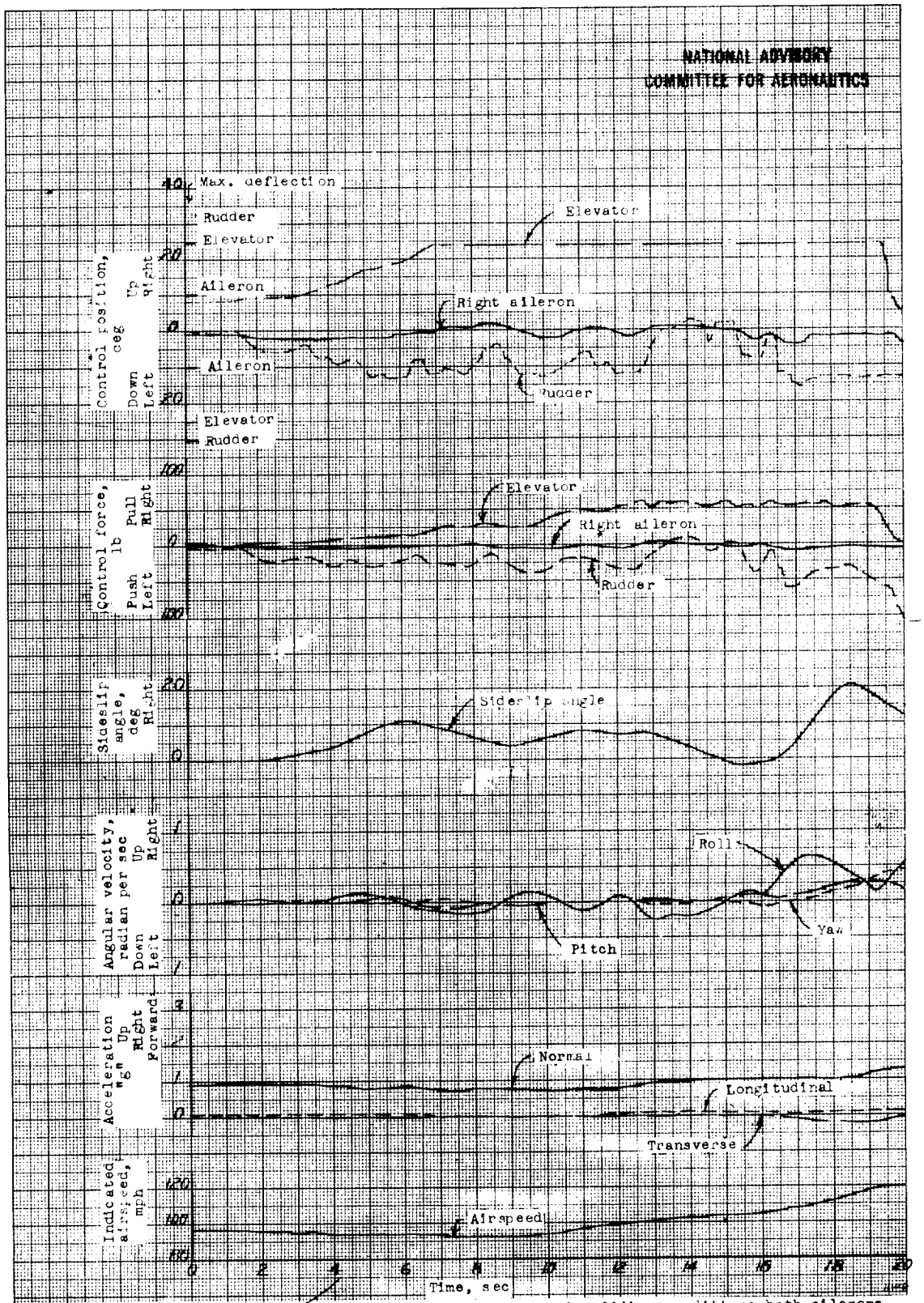

Figure 46. - Time history at stall of XP-51 airplane in gliding condition; both ailerons and rudder used for control; center of gravity at 25.5 percent M.A.C.; four 20-millimeter gun mockups. Note that control was maintained with Elevator full up.

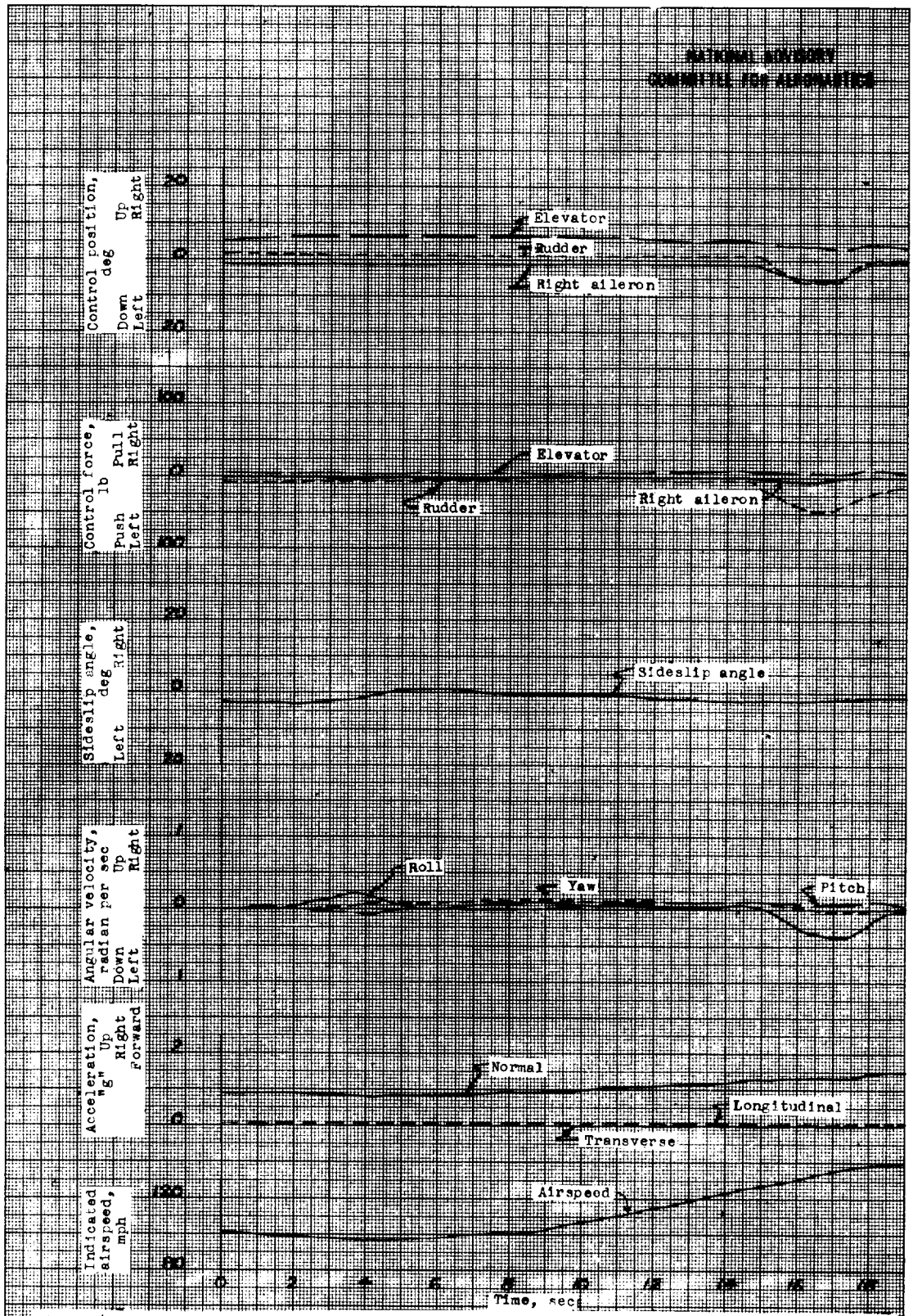

Figure 47. - Time history of stall of XP-51 airplane in gliding condition with controls fixed; center of gravity at 25.2 percent M.A.C.; wing gun ports open.

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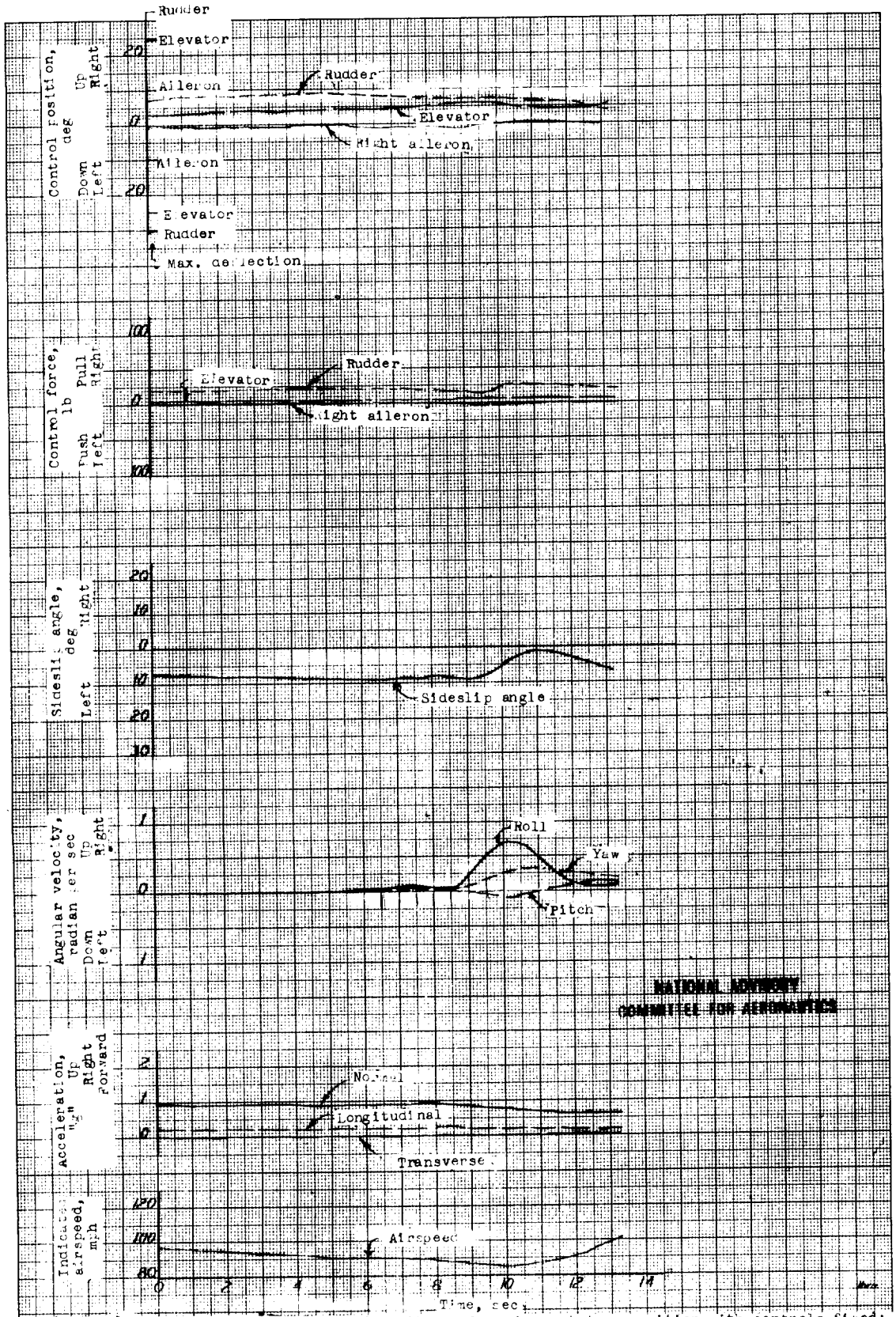

Figure 48. - Time history of stall of XB-51 airplane in cruising condition with controls fixed; center of gravity at 25.9 percent M.A.C.; clean wing.

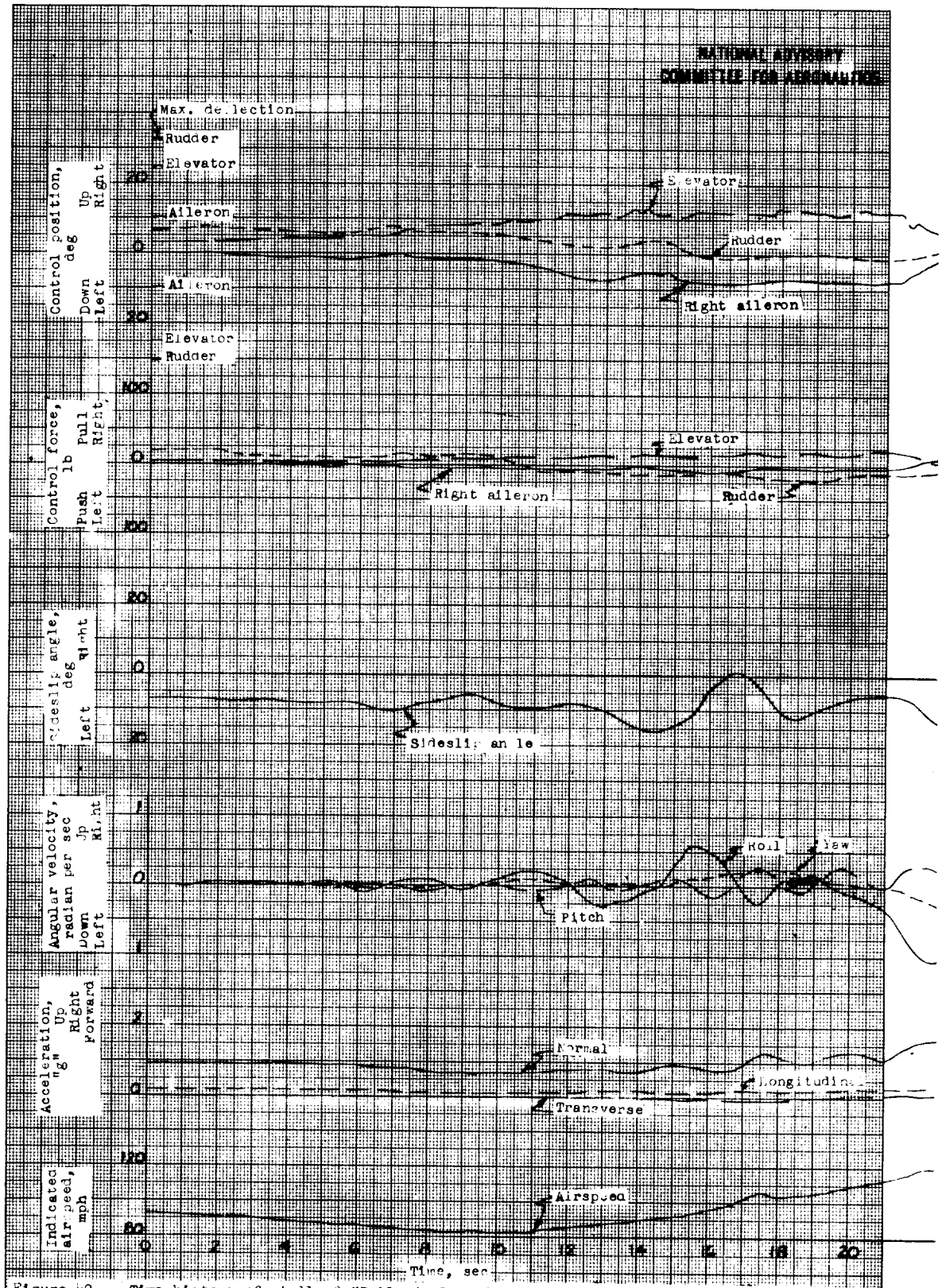

Figure 49. - Time history of stall of XP-51 airplane in cruising condition controlled principally by ailerons; center of gravity at 29.7 percent M.A.C.; clean wing.

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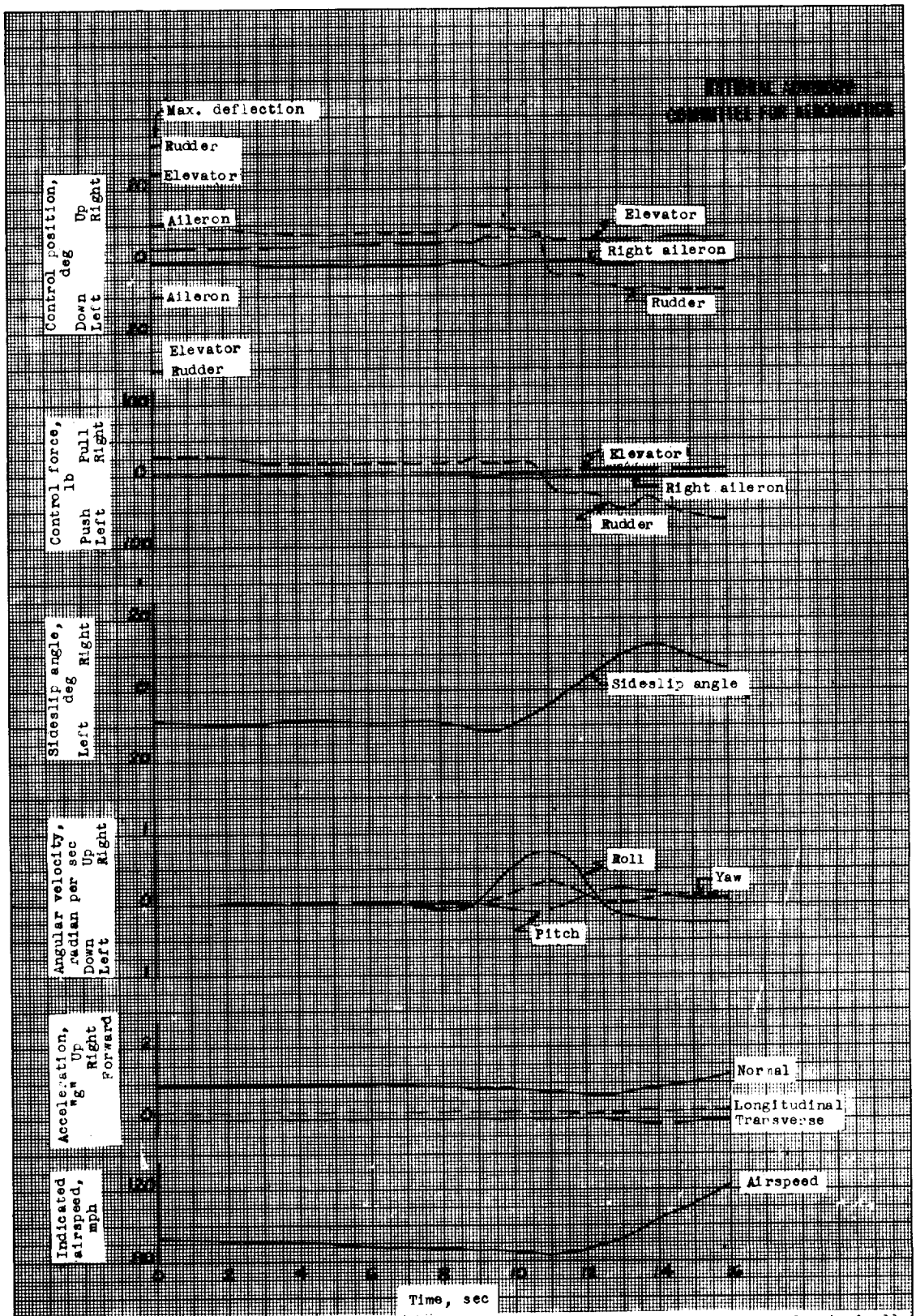

Figure 50. - Time history of stall of XP-51 airplane in cruising condition controlled principally by rudder; center of gravity at 25.8 percent M.A.C.; clean wing.

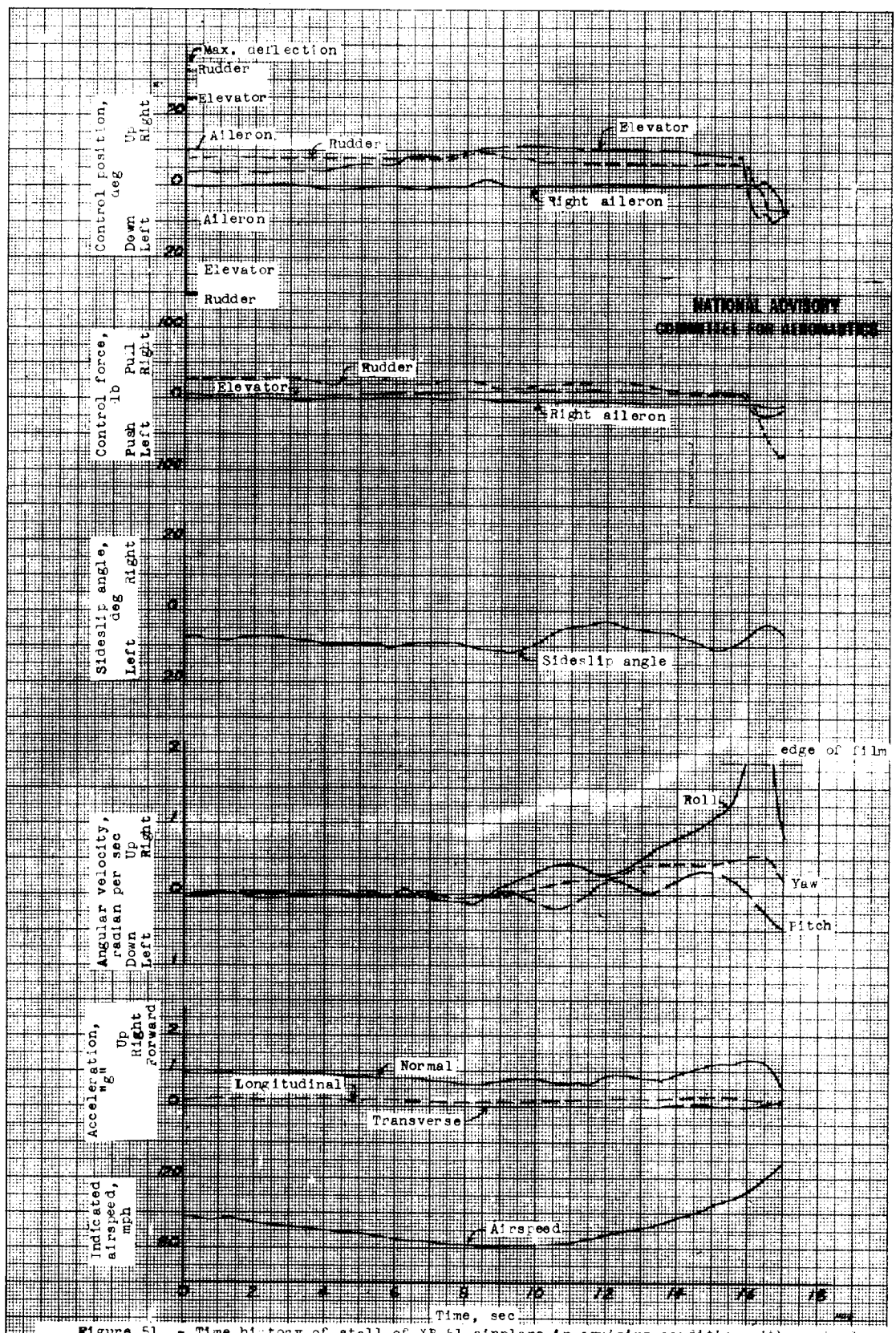

Figure 51. - Time history of stall of XP-51 airplane in cruising condition with controls fixed; center of gravity at 25.5 percent M.A.C.; four 20-millimeter gun mockups.

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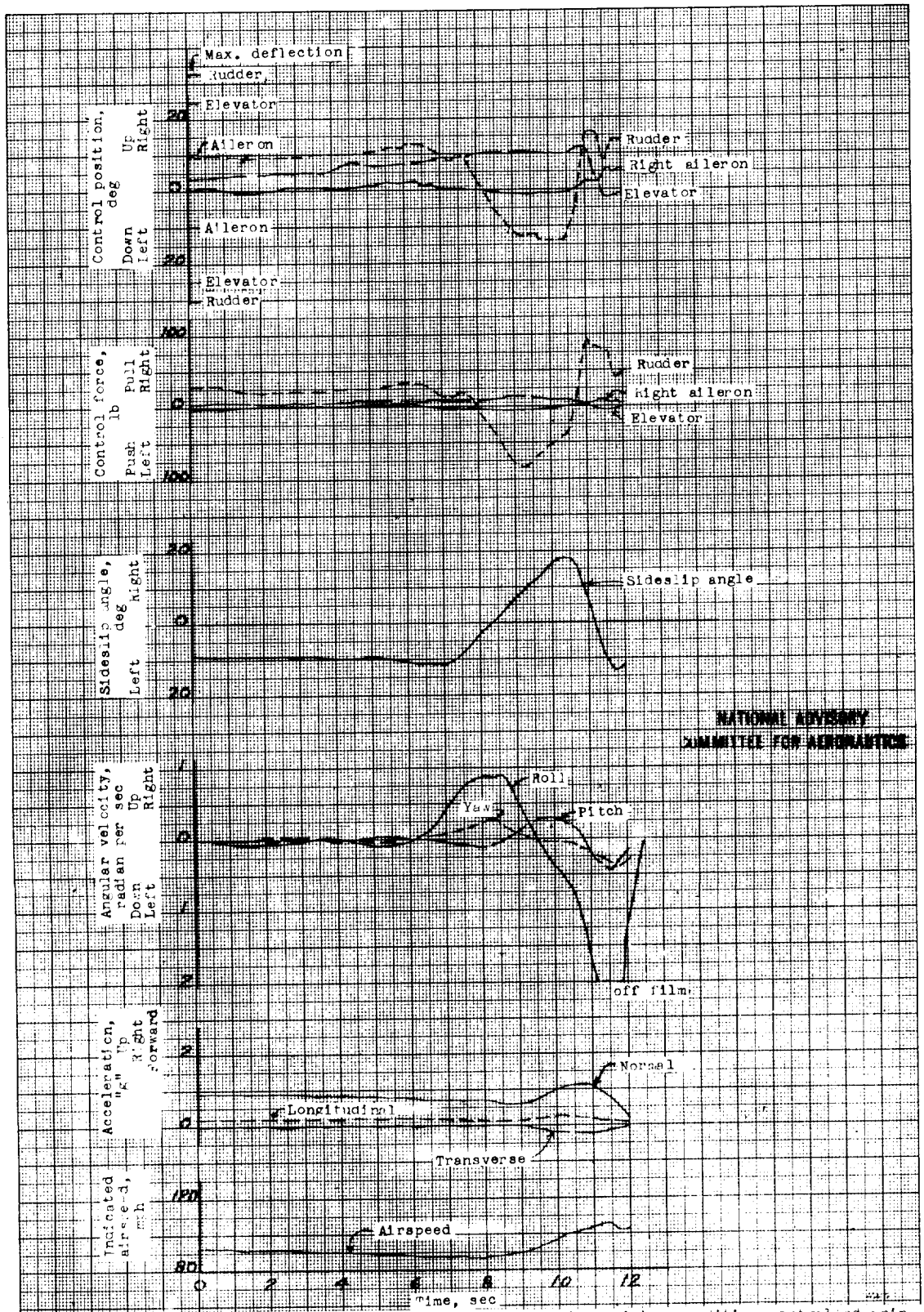

Figure 52. - Time history of stall of XP-51 airplane in cruising condition controlled principally by rudder; center of gravity at 25.6 percent M.A.C.; four 20-millimeter gun mockups.

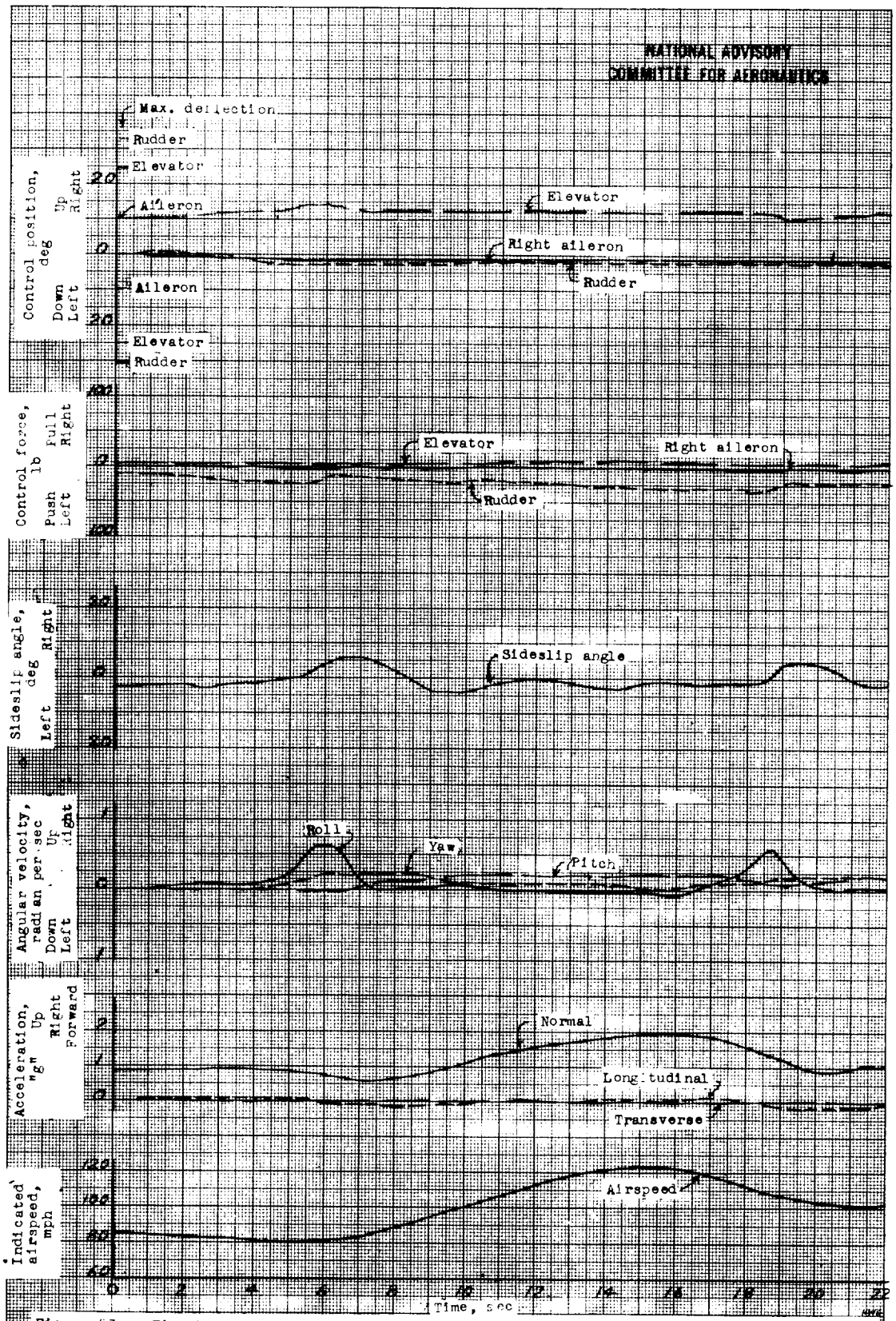

Figure 53. - Time history of stall of XP-51 airplane in landing condition with controls fixed; center of gravity at 24.7 percent M.A.C.; clean wing.

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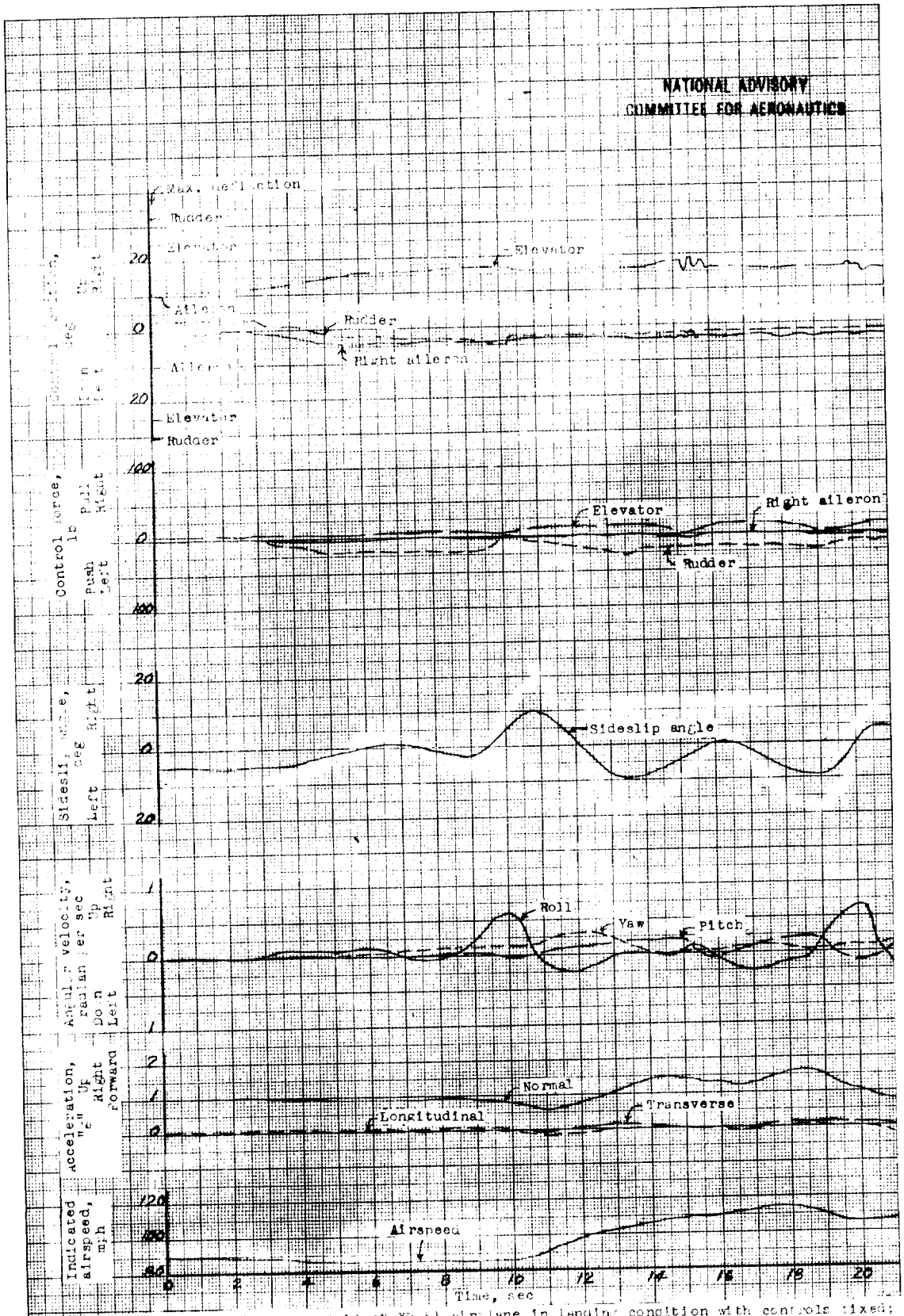

Figure 54. - Time history of stall of XP-51 airplane in landing condition with controls fixed; center of gravity at 24.7 percent M.A.C.; four 20-millimeter gun mockups.

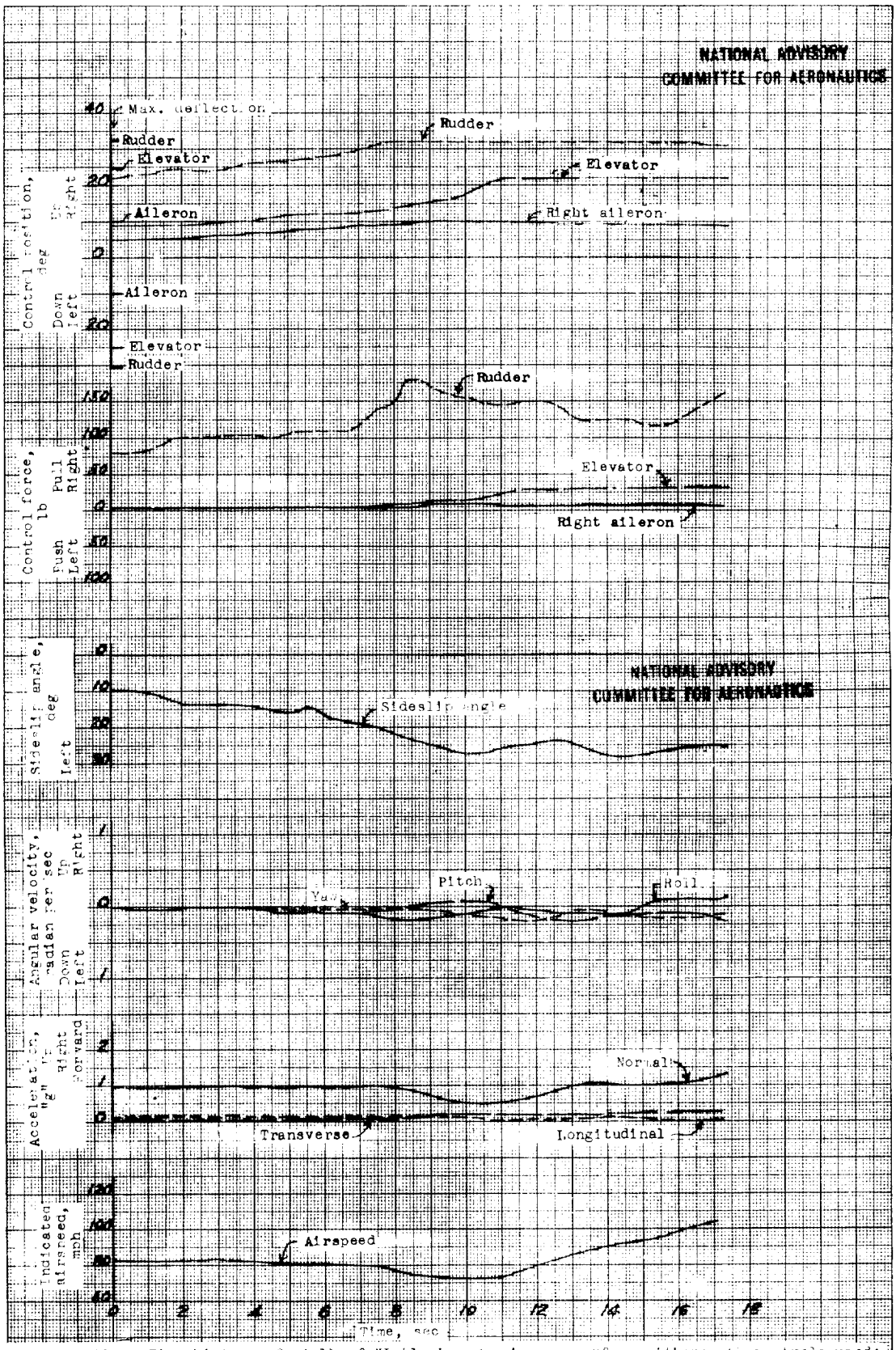

Figure 55. - Time history of stall of XP-51 airplane in wave off condition; all controls used; center of gravity at 24.2 percent M.A.C.; clean wing. Note that maximum rudder and maximum aileron were inadequate to restrain airplane from yawing.

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