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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

FLIGHT MEASUREMENTS OF THE DIRECTIONAL STABILITY AND CONTROL OF A P-51D AIRPLANE WITH A HORN-BALANCED RUDDER AS COMPARED WITH PREVIOUSLY TESTED VERTICAL-TAIL CONFIGURATIONS

By

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FLIGHT MEASUREMENTS OF THE DIRECTIONAL STABILITY AND CONTROL OF A P-51D AIRPLANE WITH A HORN-BALANCED RUDDER AS COMPARED WITH PREVIOUSLY TESTED VERTICAL-TAIL CONFIGURATIONS

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SUMMARY

Flight tests were made to determine the directional stability and control of a P-51D-20-NA airplane equipped with a horn-balanced rudder. The characteristics of the horn-balanced rudder are compared with those of the original production and extended tail configurations. Previous tests showed that the P-51D series airplanes with the original production tail had poor directional stability at small angles of sideslip and had a large change in rudder trim force with speed. The tests conducted on the extended tail configuration indicated that this modification improved the directional stability to the extent of being considered acceptable.

The directional stability with rudder free of the airplane with a horn-balanced rudder was greater than that with the original production tail configuration and approximately equal to the value obtained with the extended tail configuration. The directional stability with rudder fixed of the airplane with the horn-balanced rudder was no greater than that with the original tail and was less at higher speeds. The lack of rudder-fixed directional stability resulted in difficulty in maintaining steady conditions at high speeds. No rudder lock was encountered with the horn-balanced rudder. The change in trim force with speed for the horn-balanced rudder was less than that with the original-tail configuration and approximately equal to that with the extended tail configuration. Lateral oscillations of the airplane with the horn-balanced rudder were damped at all speeds except at 130 miles per hour, where a continuous oscillation occurred. This continuous oscillation

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occurred at 25,000 feet altitude was not attributed to the characteristics of the horn-balanced rudder because the rudder returned to neutral and remained there during the oscillation.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, flight tests were conducted on a P-51D-20-NA (AAF No. 44-63826) airplane equipped with a horn-balanced rudder. The rudder was fitted with an unbalancing tab as was the original production rudder. Tests were made both with the unbalancing tab in operation and with the unbalancing tab locked. The modification to the original vertical tail consisted of removing the cap from the top of the fin and adding 1.91 square feet of area to the rudder as the horn balance and 0.82 square foot of area to the top of the rudder aft of the hinge line.

A comparison of the directional stability and control characteristics of the P-51D airplane with three different vertical-tail configurations - the horn balance, original production, and extended tail (with unbalancing tab locked) configurations are presented herein. The tests of the horn-balanced rudder were conducted at the Langley Laboratory in 1945. The tests of the original-tail configuration were previously conducted at the Ames Aeronautical Laboratory (reference 1). Tests of the extended-tail configuration were conducted at the Langley Laboratory and are reported in reference 2.

AIRPLANE

The P-51D-20-NA airplane is a single-place, low wing, fighter-type monoplane. A three-view drawing of the airplane as tested is shown in figure 1. A side view of the airplane is shown in figure 2. Figures 3 and 4 show the comparison between the original production, extended tail and horn-balanced rudder configurations tested. Figure 5 is a drawing comparing the rudders of the three airplanes.

General Specification and Dimensions

Engine . . . . Packard V-1650-7

Rating:

Take-off (61 in. Hg 3000 rpm) horsepower	1500
Normal (46 in. Hg 2700 rpm) (at sea level) horsepower . .	1000

Propeller	Hamilton Standard Hydromatic
Diameter	11 ft 2 in.
Number of blades	4
Gear ratio	2.09:1
Gross weight as tested (at take-off) lb	8742
Center-of-gravity position (wheels down) percent M.A.C.	25.5
Wing:	
Span	37 ft $\frac{5}{16}$ in.
Area, sq ft	240
Taper ratio	2.16:1
Section	NAA - NACA low drag airfoil
Dihedral, deg	5
Sweepback (leading edge)	$3^{\circ}\ 35'\ 32''$
Vertical tail (production):	
Total area, sq ft	20.02
Fin area (exclusive of dorsal fin, sq ft)	9.61
Fin offset from fuselage center line	1° left
Rudder deflection, from fin, deg	± 30
Rudder trim tab area, sq ft	0.81
Rudder trim tab deflection, deg	± 10
Ratio of unbalancing tab deflection to rudder deflection, approximate	right rudder 0.6:1
	left rudder 0.4:1
Vertical tail (horn balanced):	
Total area, sq ft	20.75

Note: All other dimensions are the same as for the production configuration.

INSTRUMENTATION

Standard NACA recording instruments were used to measure rudder position, rudder pedal force, sideslip angle, and airspeed. The airspeed head was a swivel type, mounted 1 chord length ahead of the right wing tip. This installation was not calibrated for position error. Service indicated airspeed V_{i_s} as used in this report is defined by the formula:

$$V_{i_s} = 45.08\, f_o \sqrt{q_c}$$

where

f_o the compressibility correction factor at sea level

q_c the impact pressure, measured as the difference between total head and static pressure in inches of water

The yaw vane for use with the recorder was mounted 1 chord length ahead of the left wing tip.

TESTS, RESULTS, AND DISCUSSION

Measurements were made in flight of the directional stability in sideslips and the change in rudder-trim force with speed at 10,000 and 25,000 feet altitude of the P-51D-5-NA with the horn-balanced rudder and fitted with an unbalancing tab. Additional tests at 10,000 feet altitude were made with the unbalancing tab locked. All tests were made in the climbing condition (normal rated power, flaps and landing gear up). To maintain a normal center-of-gravity position of 25.5 percent of the mean aerodynamic chord throughout the tests the fuselage fuel tank was kept empty. The change of center-of-gravity position due to fuel consumption during flight was negligible.

The directional stability was determined by measuring the rudder deflection, pedal force and sideslip angle during slow continuous sideslips, in which the rudder was deflected at a continuous rate to the right and left at given indicated airspeeds of approximately 103, 200, and 350 miles per hour at 10,000 feet altitude and 100, 250, and 350 miles per hour at 25,000 feet altitude. Data obtained at these altitudes for the horn-balanced rudder, the original vertical-tail configurations, and the extended-tail configurations are given in comparison in figures 6 to 8 and 9 to 11, respectively. Figures 12 to 14 are the data for the horn-balanced rudder with the unbalancing tab locked at 10,000 feet. All rudder angles are given in degrees from the center line of the airplane.

The horn-balanced rudder increased the rudder-free stability but gave a negligible increase in the rudder-fixed stability when compared with the original tail. A comparison of the values of variation of rudder angle with sideslip $d\delta_r/d\beta$ and the variation of rudder force with sideslip $dF_r/d\beta$ for all three of the configurations is given in table I. The value of $d\delta_r/d\beta$ is a measurement of the rudder-fixed directional stability, and the value of $dF_r/d\beta$ is a measurement of the rudder-free directional stability. From table I it appears that the values of $d\delta_r/d\beta$ for the horn-balanced rudder decreased with increasing speed and at high speed became less than those for the original-tail configuration. The value of $d\delta_r/d\beta$ for all tail configurations tended to decrease slightly in going from 10,000 to 25,000 feet altitude. Because of the difficulty in accurately measuring the slopes of the curves of rudder deflection against sideslip angle over a small range of sideslip angles, the values given in table I are only approximate.

Values of $dF_r/d\beta$ for the horn-balanced rudder and extended tail showed a normal increase with increasing speed while the values for the original tail decreased as the speed increased from 200 to 350 miles per hour at 10,000 feet altitude. The value of $dF_r/d\beta$ for the horn-balanced rudder was generally equal to that of the extended tail whereas, the value for the original tail was considerably less.

For the horn-balanced rudder with unbalancing tab locked at 10,000 feet altitude, the value of $d\delta_r/d\beta$ decreased as the speed increased from 200 to 350 miles per hour. The value of $dF_r/d\beta$ showed a normal increase with increasing speed. The value of $d\delta_r/d\beta$ was greater with the unbalancing tab locked than with it in operation. This increase is due to the fact that rudder effectiveness is reduced with the tab locked. As expected, the value of $dF_r/d\beta$ was decreased when the unbalancing tab was locked. With the unbalancing tab locked no overbalancing or tendency toward rudder lock was encountered.

Measurements of the rudder angle and force required to maintain straight flight with the wings level were taken starting from near stall through the speed range. The low altitude test was started near stalling speed at 15,000 feet and the indicated airspeed was increased in a shallow divo until 430 miles per hour was reached at 8000 feet. At high altitude a shallow dive was started near stall at 30,000 feet until 391 miles per hour was indicated at 20,000 feet altitude. Data obtained from these tests are shown in figures 15 and 16. Also given in these figures are curves obtained from tests conducted on the original-tail and extended-tail configurations. It was noted that with the horn-balanced rudder the pilot did not keep zero sideslip throughout the dive and the scatter in the force data is due to the difficulty the pilot had in holding conditions steady. The airplane was not trimmed at the same speed in the three sets of tests, but the data indicate that if the characteristics were compared under similar trim conditions, the rudder force variation with speed would be the greatest for the original tail. The horn-balanced rudder and extended tail configurations would have similar force characteristics except at high speeds, where the extended tail would have somewhat smaller forces. At high altitude, the change in trim force with speed for the horn-balanced rudder appeared to be less than that of the extended tail as shown in figure 16. The pilot had the same difficulty holding conditions steady throughout the run at high altitude as he did at low altitude, thus causing the scatter in the data for the horn-balanced rudder. The difficulty in maintaining steady conditions at high speeds was attributed to the low rudder-fixed directional stability of the airplane. The change in rudder position throughout the dive, for low and high altitude, is approximately the same, as shown by figures 15 and 16.

In order to determine the hinge-moment characteristics of the horn-balanced rudder, rudder kicks were made in which the pilot abruptly deflected and held the rudder. These tests were made at altitudes of 10,000 and 25,000 feet and at speeds of 150, 250, and 350 miles per hour. The variation of the rudder hinge-moment coefficient with deflection $dC_h/d\beta$ was determined from the rudder force initially required to deflect the rudder. The variation of rudder hinge-moment coefficient with angle of attack $dC_h/d\beta$ was determined from the change in rudder force as the sideslip angle increased. These values of $dC_h/d\delta$ and $dC_h/d\alpha$ are presented in table II. From the calculated values, it may be seen that $dC_h/d\alpha$ for the horn-balanced rudder was approximately zero. The unbalancing tab appeared to increase the value of $dC_h/d\delta$ from about -0.007 to -0.009.

Lateral oscillations were made at high and low altitude by deflecting the rudder at a rapid rate and releasing it. These tests were made at altitudes of 10,000 and 25,000 feet and at speeds of 130, 150, 250, and 350 miles per hour. The records showed that the oscillations damped satisfactorily in all runs except those at 130 miles per hour. A time history of a typical oscillation is shown in figure 17. The rudder returned rapidly to its trim position when released and remained there during the oscillations. An undamped lateral oscillation occurred at an indicated airspeed of 130 miles per hour at 25,000 feet altitude. Figures 18 and 19 show time histories of the undamped oscillations. The undamped lateral oscillation was accompanied by a spiral divergence and an increase in the indicated airspeed. When the speed increased the oscillations damped rapidly. There was no tendency for a snaking oscillation, in which the rudder motion reinforces the motion of the airplane. The rudder position record showed that the rudder remained essentially fixed during the oscillation, so that the lack of damping cannot be attributed to the characteristics of the horn-balanced rudder.

This type of oscillation, which has been observed on other high-powered single-engine airplane, involves a combination of lateral and longitudinal oscillations, and is believed to be caused by the gyroscopic effect of the propeller. The pilot did not consider this undamped oscillation to be objectionable because it was easily controlled.

The pilots considered the control force characteristics of the horn-balanced rudder to be as good as those of the extended tail configuration and an improvement over the original tail. They objected to the difficulty in keeping the directional control steady during the dives at high speeds.

CONCLUSIONS

An investigation was made of the directional stability of a P-51D-20-NA airplane with a horn-balanced rudder. The results of these tests were compared with those of previous tests of the airplane with original production tail and with an extended tail. The following conclusions were obtained from this investigation:

1. The directional stability of the airplane rudder free as indicated by the variation of rudder force with sideslip angle was greater with a horn-balanced rudder than that with the original production tail configuration and approximately equal to the value obtained with the extended-tail configuration. No rudder lock was encountered with the horn-balanced rudder.

2. The directional stability of the airplane with rudder fixed as indicated by the variation of rudder angle with sideslip was no greater and less at higher speeds with a horn-balanced rudder than with the original production tail and considerable less than that with the extended tail.

3. The change in trim force with speed for the horn-balanced rudder was less than that produced by the original-tail configuration and approximately the same as that of the extended-tail configuration, which is considered acceptable.

4. The horn-balanced rudder did not cause any tendency for a snaking oscillation.

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National Advisory Committee for Aeronautics
Langley Field, Va.

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Aeronautical Engineer

Approved:
Melvin N. Gough
Chief of Flight Research Division

mhs

REFERENCES

1. Skoog, Richard B., and Nissen, James M.: A Flight Investigation of the Directional Stability and Control Characteristics of a P-51D Airplane with Minor Modifications to the Fin and Rudder. NACA MR, Army Air Forces, June 6, 1944.

2. Williams, Walter C., and Hoover, Herbert H.: Flight Measurements of the Directional Stability and Control of a P-51D-5-NA Airplane (AAF No. 44-13297) with a High-Aspect-Ratio Vertical Tail. NACA MR No. L5E05b, Army Air Forces, 1945.

TABLE I

SUMMARY OF THE STICK-FREE AND STICK-FIXED STABILITY AS TAKEN ±1° SIDESLIP

[The condition for which all these values were obtained was clean condition (flaps and gear up)]

Altitude	V_{i_s}	$d\delta_r/d\beta$				$dF_r/d\beta$			
		Original tail	Extended tail	Horn balance	Horn balanced with fixed tab	Original tail	Extended tail	Horn balance	Horn balanced with fixed tab
10,000	103	0.46	0.93	0.57	0.58	3.55	7.8	4.65	6.0
10,000	200	.55	1.25	.40	.55	7.30	14.0	15.50	11.7
10,000	350	.31	1.12	.08	.25	5.20	27.2	36.00	29.7
25,000	100	No data	.92	.54	No data	No data	9.0	8.5	No data
25,000	250	--do---	.98	.43	--do---	--do---	18.5	20.5	Do.
25,000	350	--do---	.98	.35	--do---	--do---	No data	40.0	Do.

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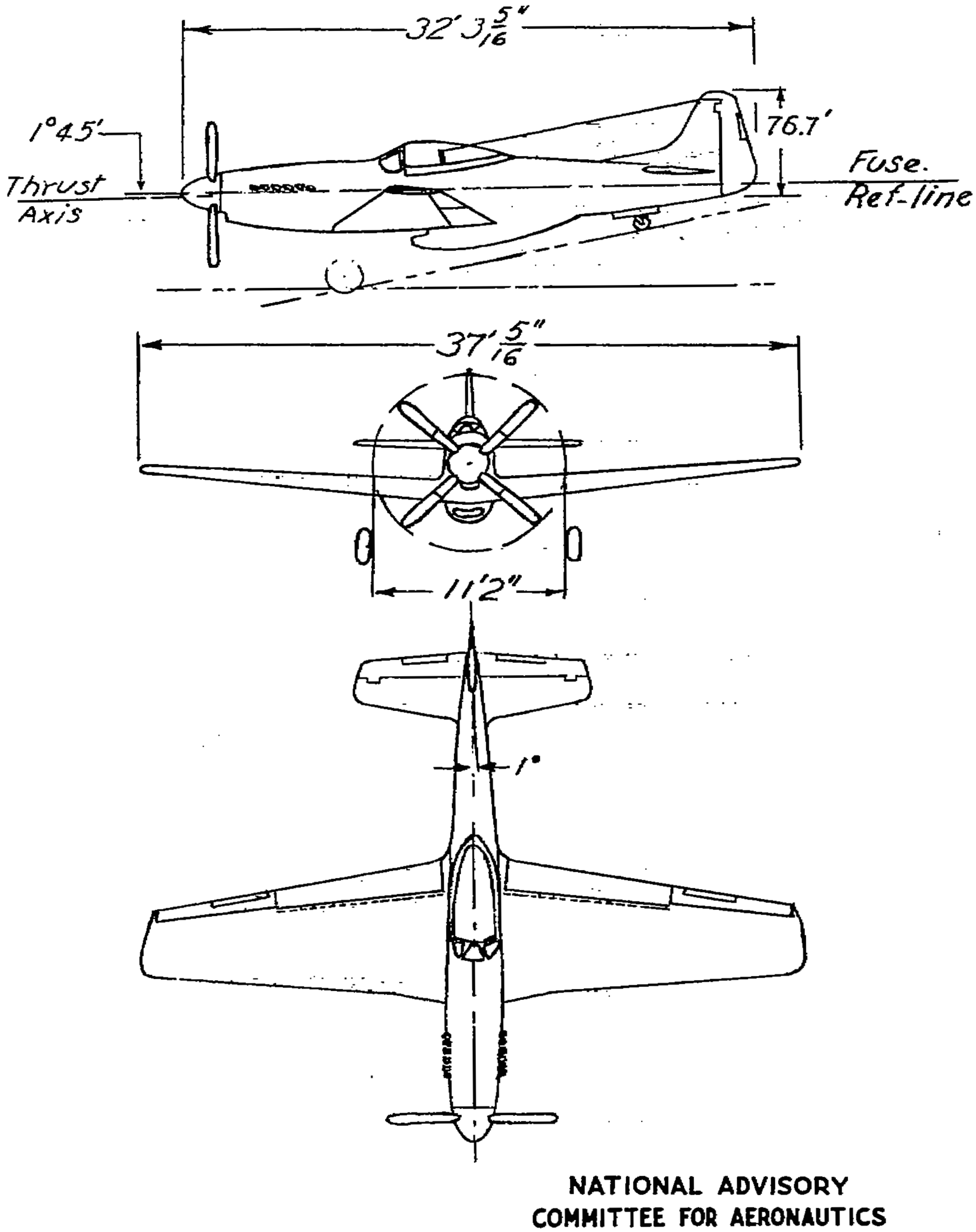

Figure 1.- Three view lay-out of the P-51D-20-NA airplane with horn balanced rudder.

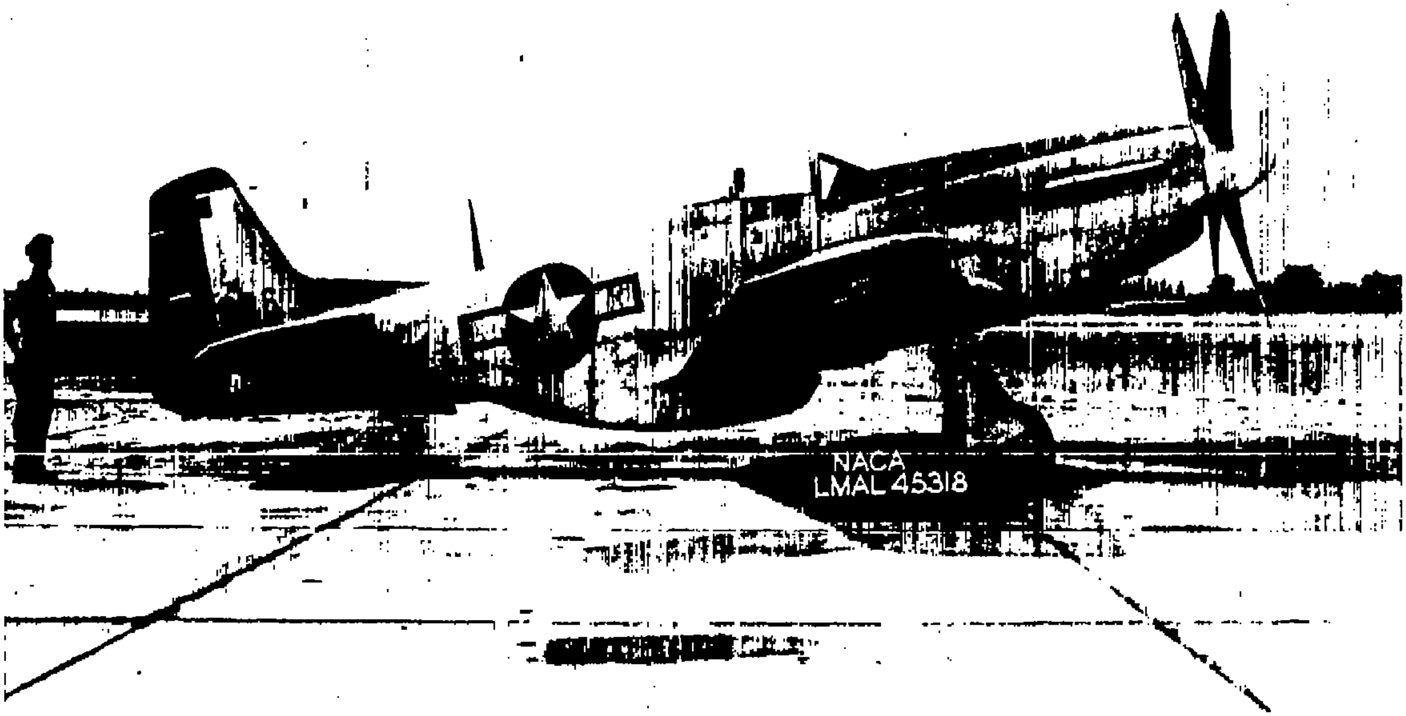

Figure 2.- Side view of the P-51D-20-NA (AAF No. 44-63826) with the horn balanced rudder.

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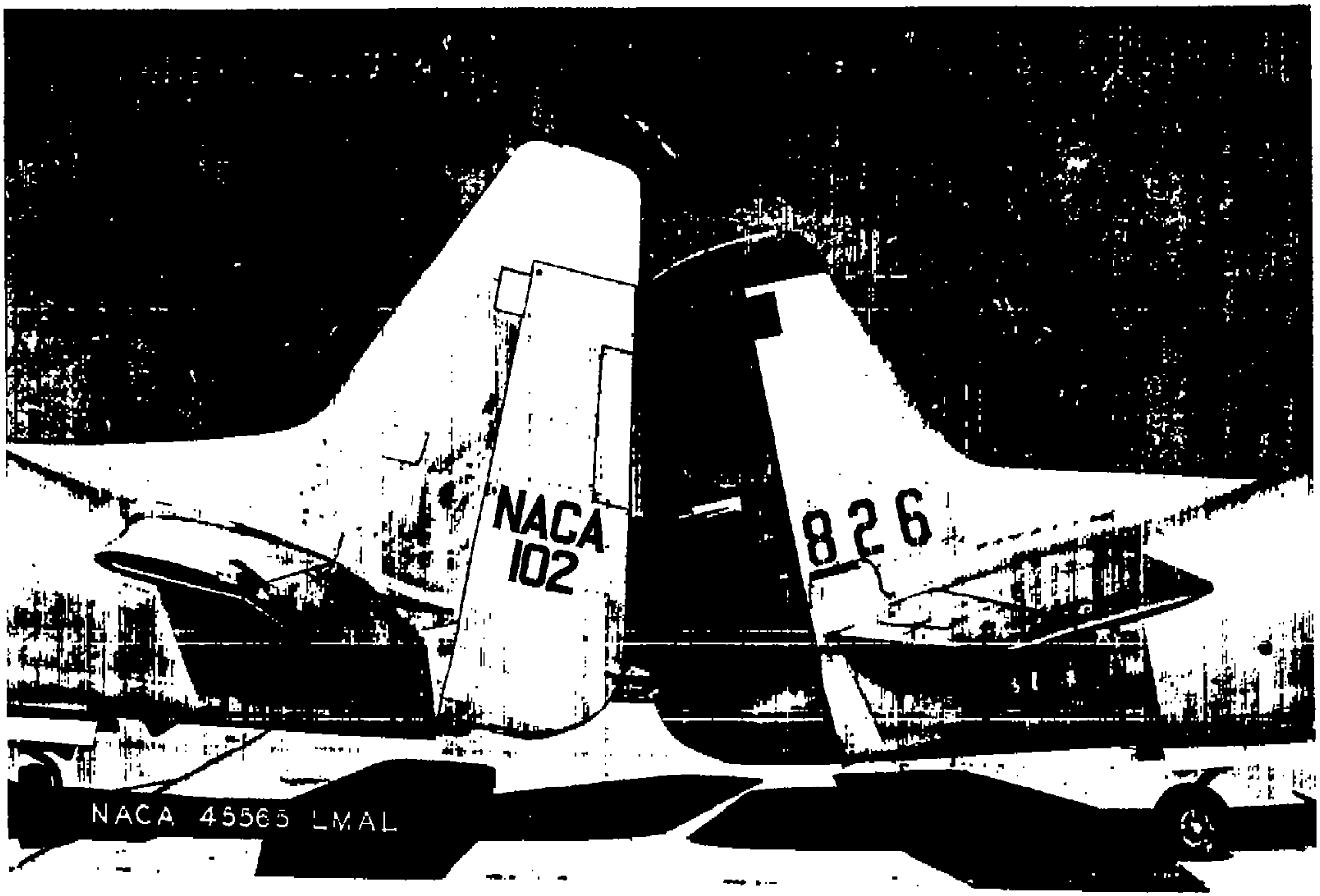

Figure 3.- Comparison of a P-51D-5-NA airplane with an extended tail and P-51D-20-NA (AAF No. 44-63826) with a horn balanced rudder.

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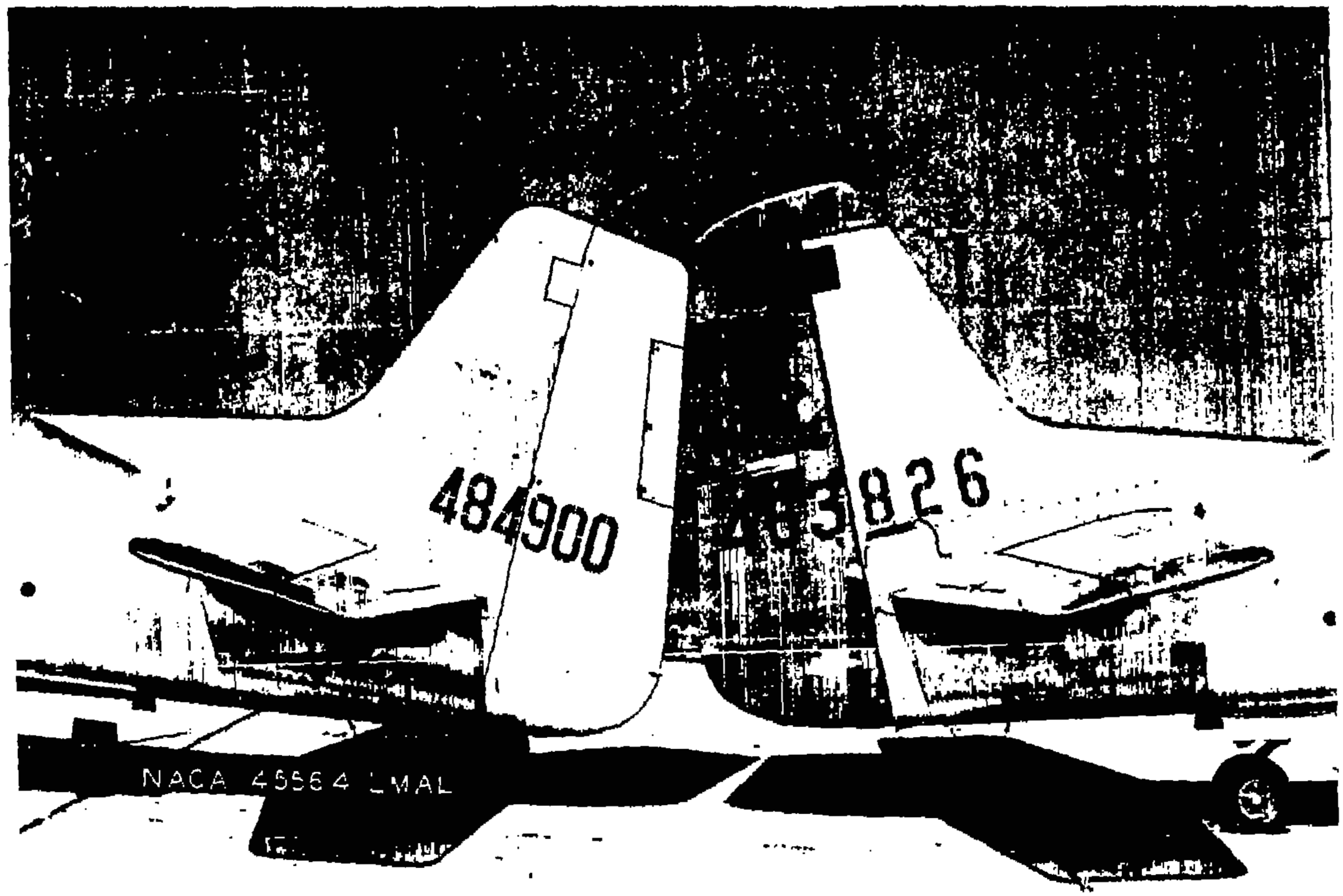

Figure 4.- Comparison of a P-51D-25-NT airplane with an original production configuration and the P-51D-20-NA (AAF No. 44-63826) with a horn balanced rudder.

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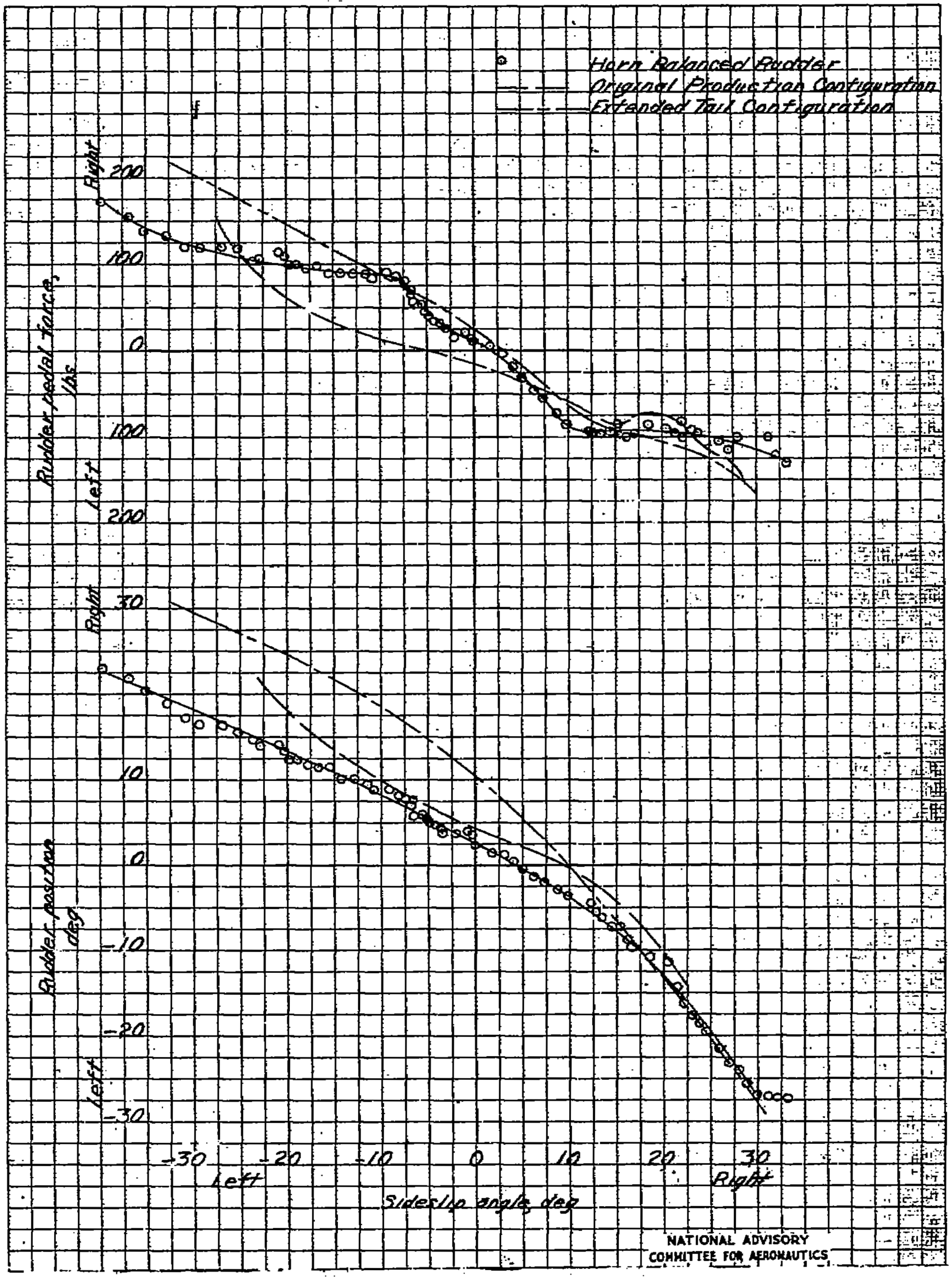

Figure 6.- Steady sideslip characteristics at 10,000 feet altitude, climbing condition V_{i_s} = 103 miles per hour. P-51D-20-NA airplane with a horn balanced rudder, original and extended tail configurations.

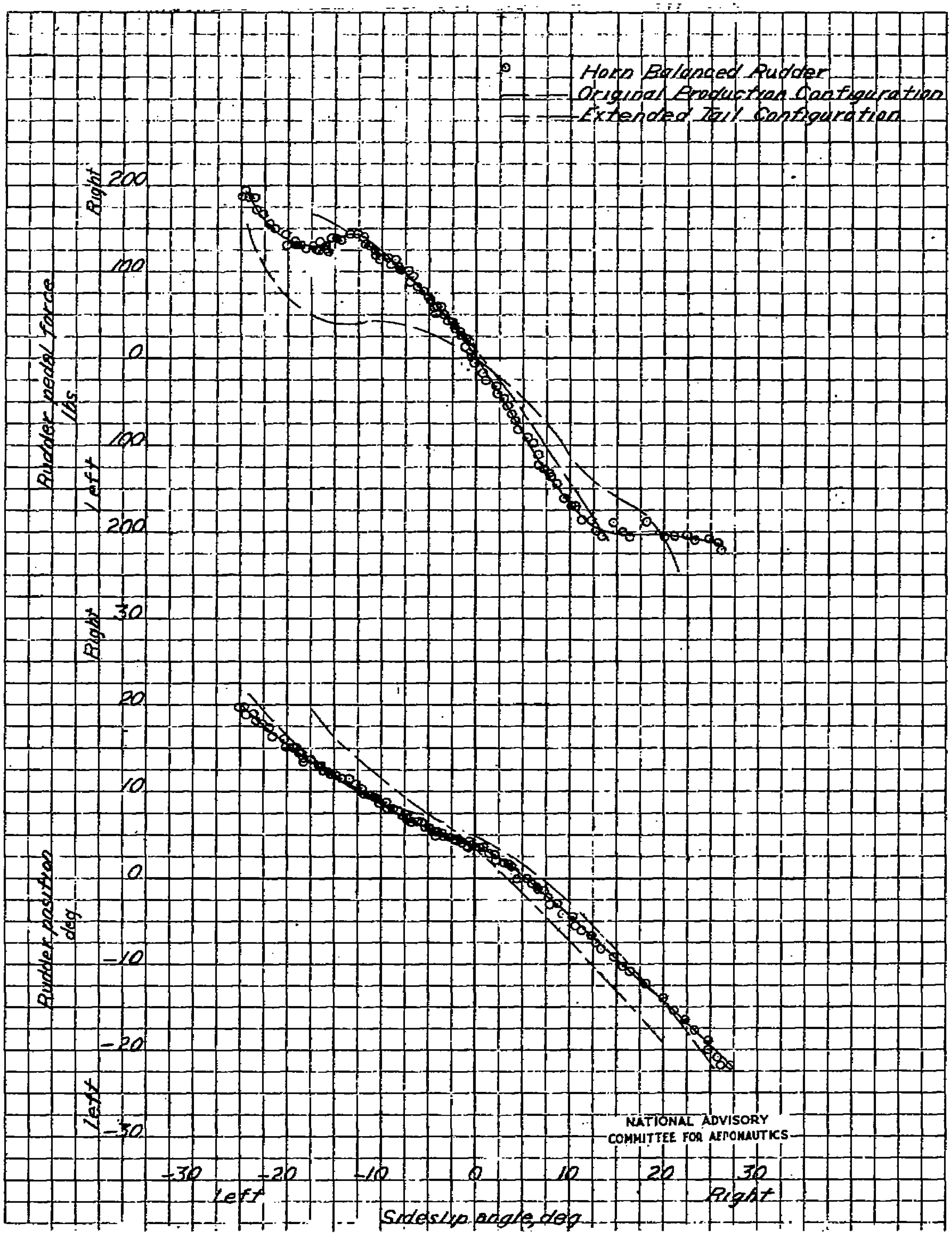

Figure 7.- Steady sideslip characteristics at 10,000 feet altitude, climbing condition V_{i_s} = 200 miles per hour. P-51D-20-NA airplane with a horn balanced rudder, original and extended tail configurations.

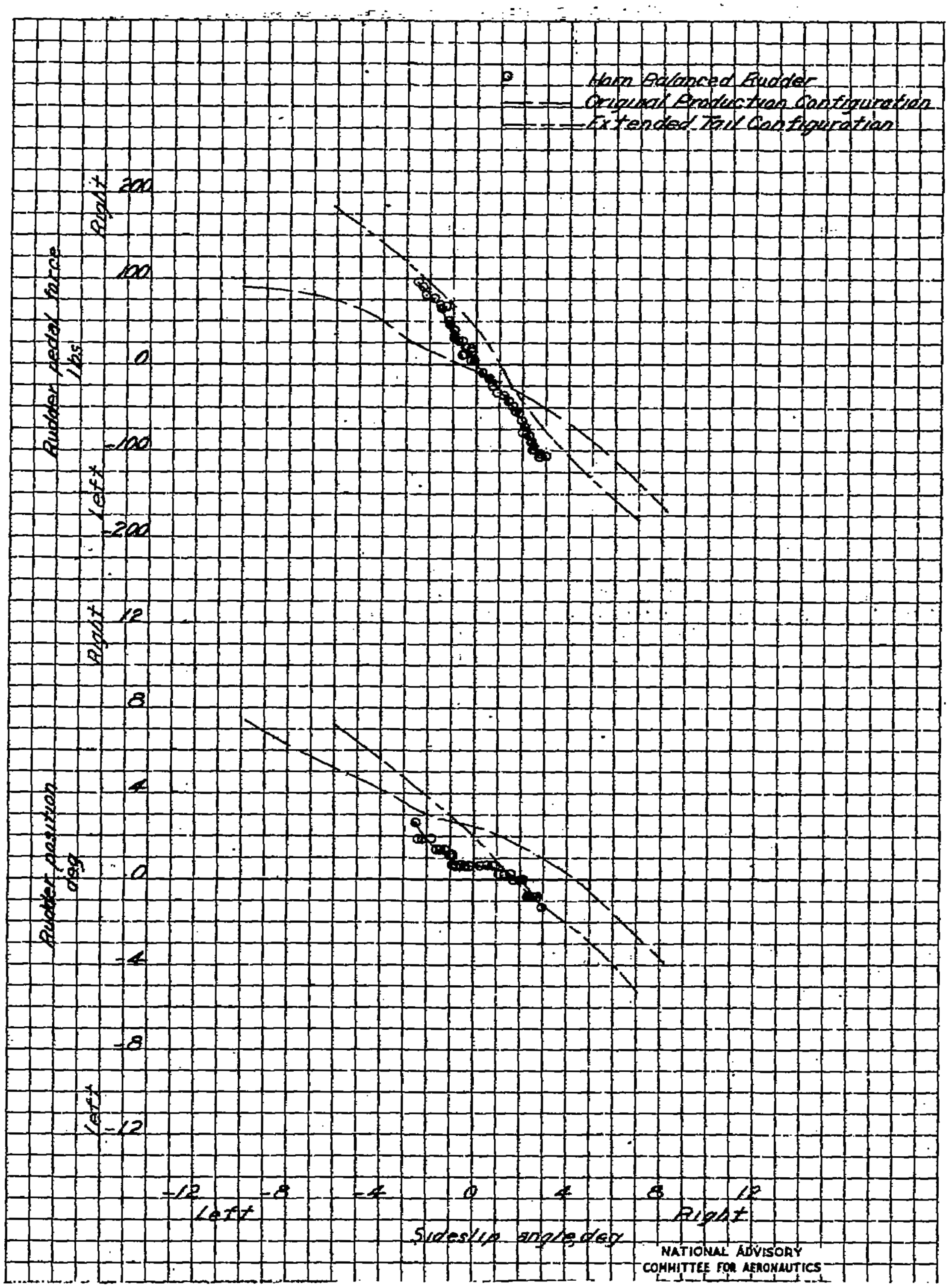

Figure 8.- Steady sideslip characteristics at 10,000 feet altitude, climbing condition V_{i_S} = 350 miles per hour. P-51D-20-NA airplane with a horn balanced rudder, original and extended tail configurations.

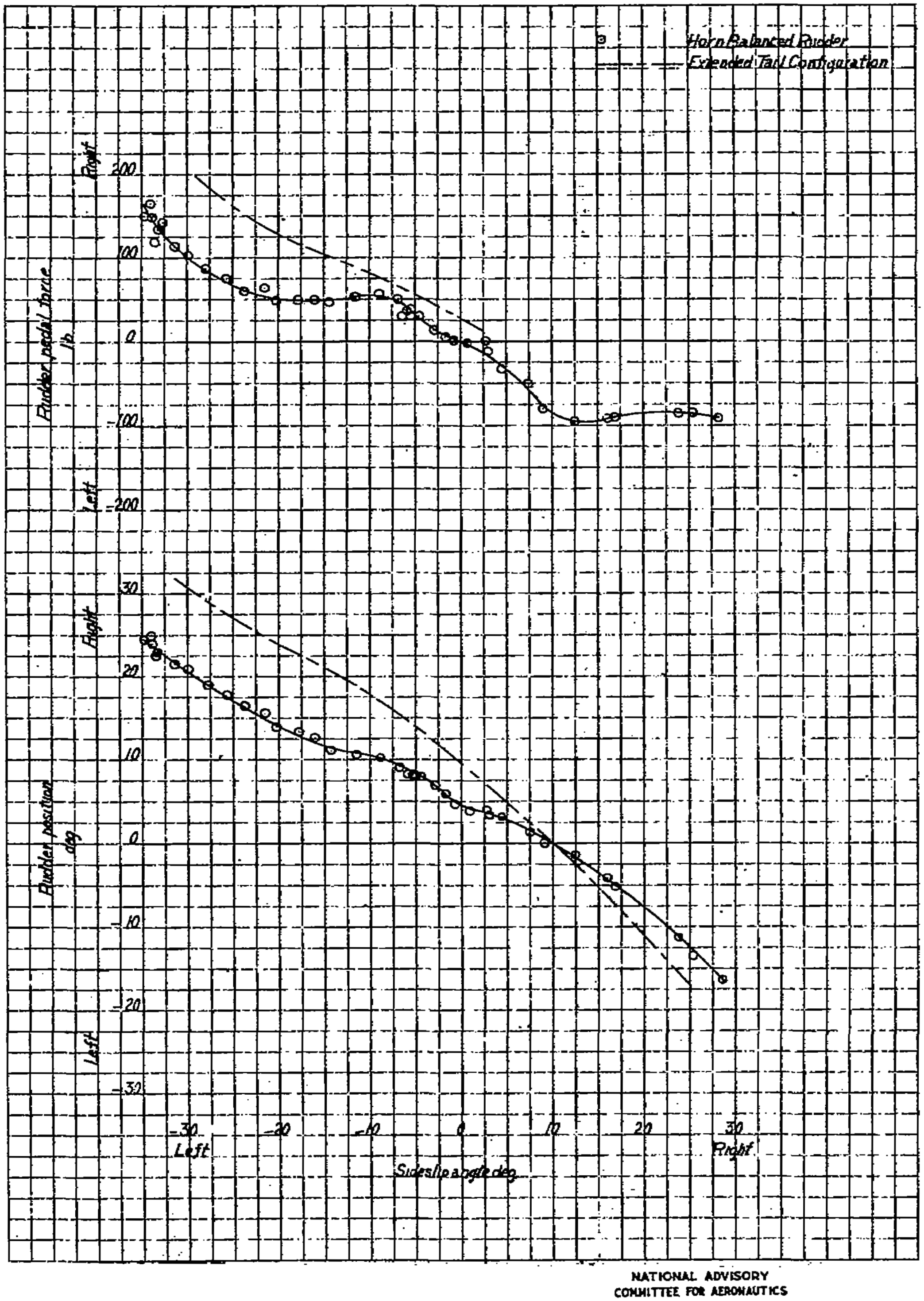

Figure 9.- Steady sideslip characteristics at 25,000 feet altitude, climbing condition V_{i_S} = 100 miles per hour. P-51D-20-NA airplane with a horn balanced rudder, and extended tail configurations.

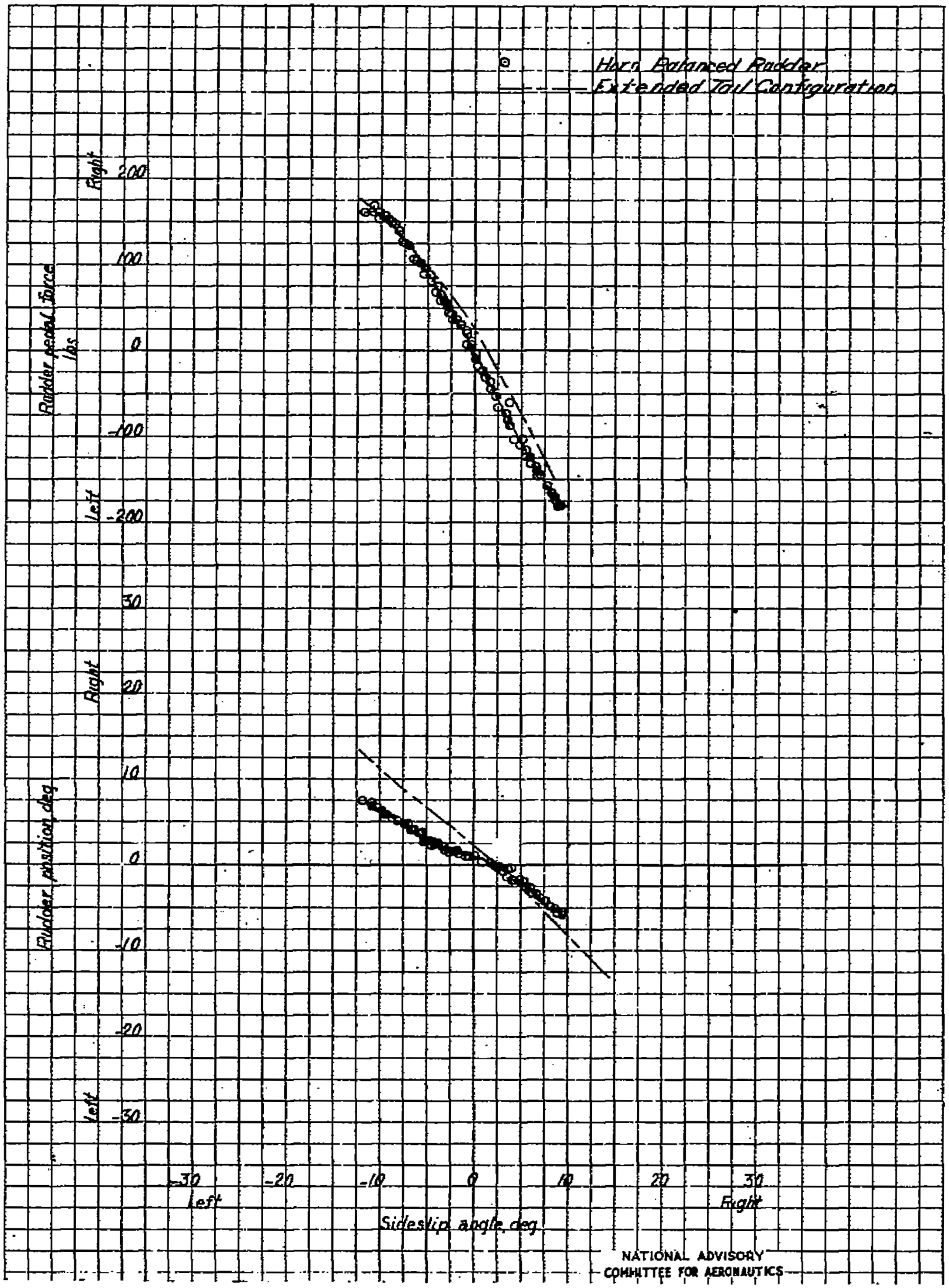

Figure 10.- Steady sideslip characteristics at 25,000 feet altitude, climbing condition V_{i_s} = 250 miles per hour. P-51D-20-NA airplane with horn balanced rudder and extended tail configuration.

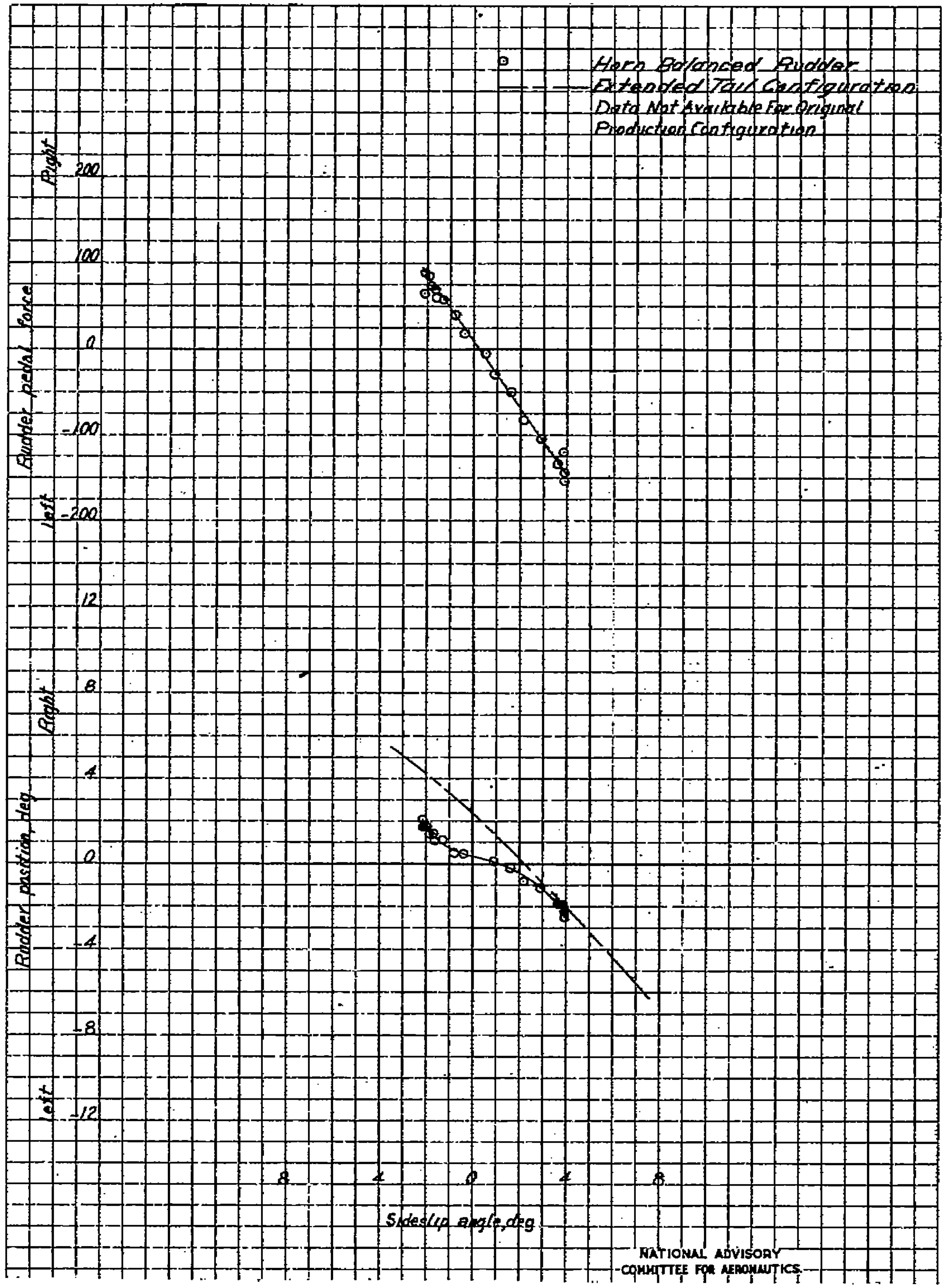

Figure 11.- Steady sideslip characteristics at 25,000 feet altitude, climbing condition V_{i_s} = 350 miles per hour. P-51D-20-NA airplane with a horn balanced rudder and extended tail.

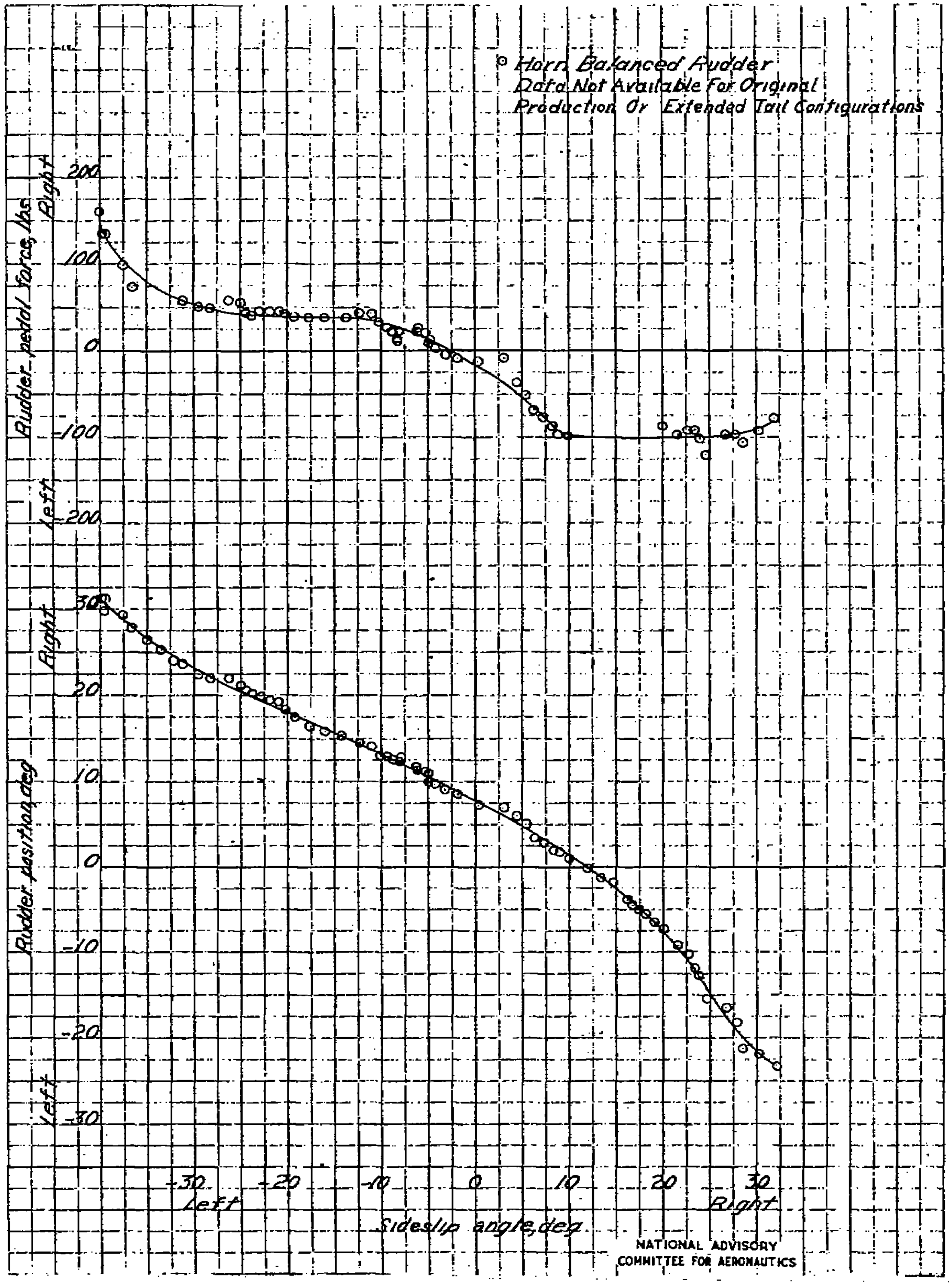

Figure 12.- Steady sideslip characteristics of 10,000 feet altitude, climbing condition V_{i_S} = 103 miles per hour. P-51D-20-NA airplane with horn balanced rudder with tab locked.

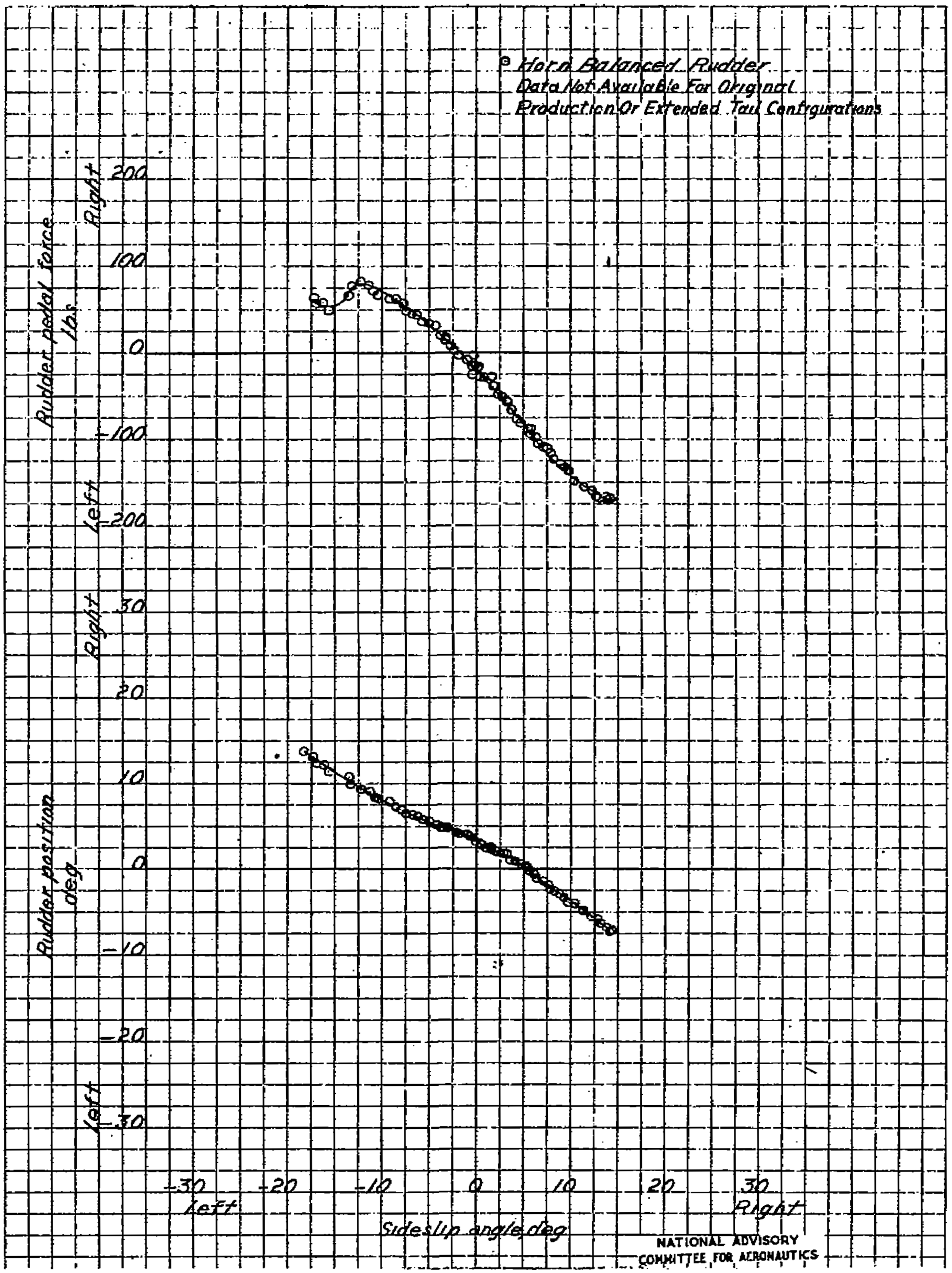

Figure 13.- Steady sideslip characteristics at 10,000 feet altitude, climbing condition V_{i_s} = 200 miles per hour. P-51D-20-NA airplane with a horn balanced rudder, tab locked.

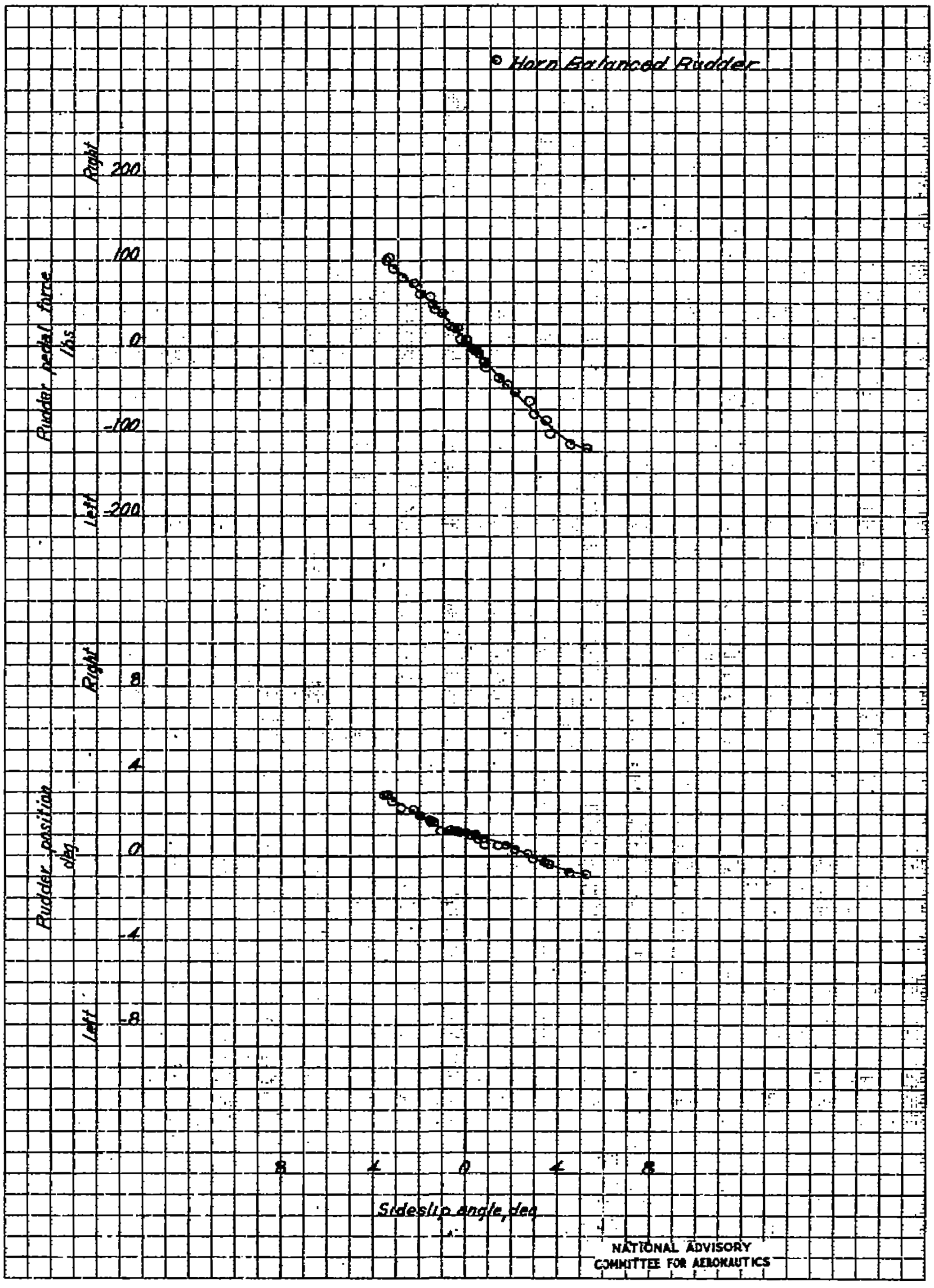

Figure 14.- Steady sideslip characteristics at 10,000 feet altitude, climbing condition V_{i_s} = 350 miles per hour. P-51D-20-NA airplane with horn balanced rudder, tab locked.

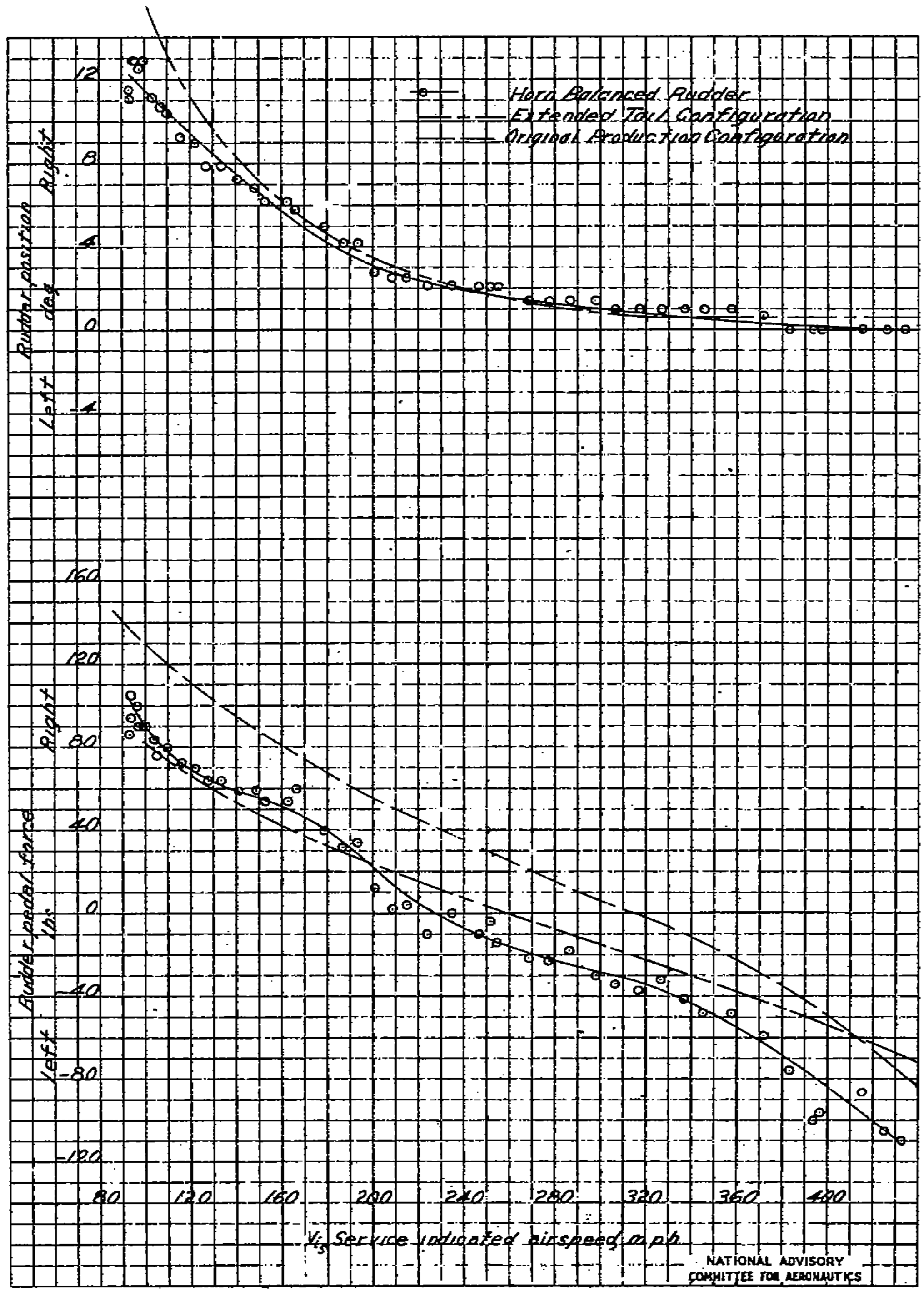

Figure 15.- Rudder trim force characteristics in diving through the speed range from 14,000 to 8,000 feet altitude. P-51D-20-NA airplane with horn balanced rudder, original and extended tail configuration.

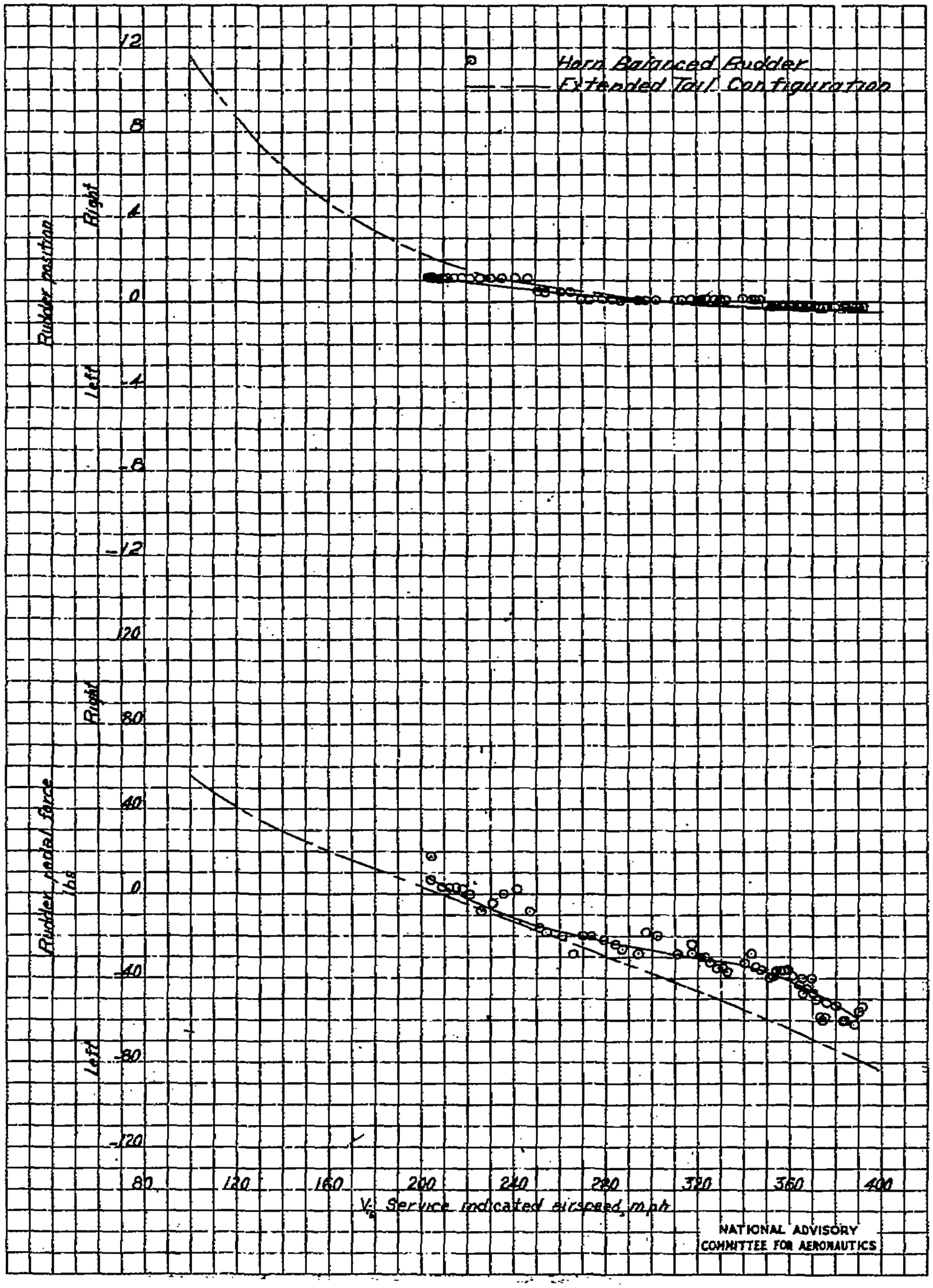

Figure 16.- Rudder trim force characteristics in a dive through the speed range from near 30,000 to 20,000 feet altitude. P-51D-20-NA airplane with a horn balanced rudder and extended tail configuration.

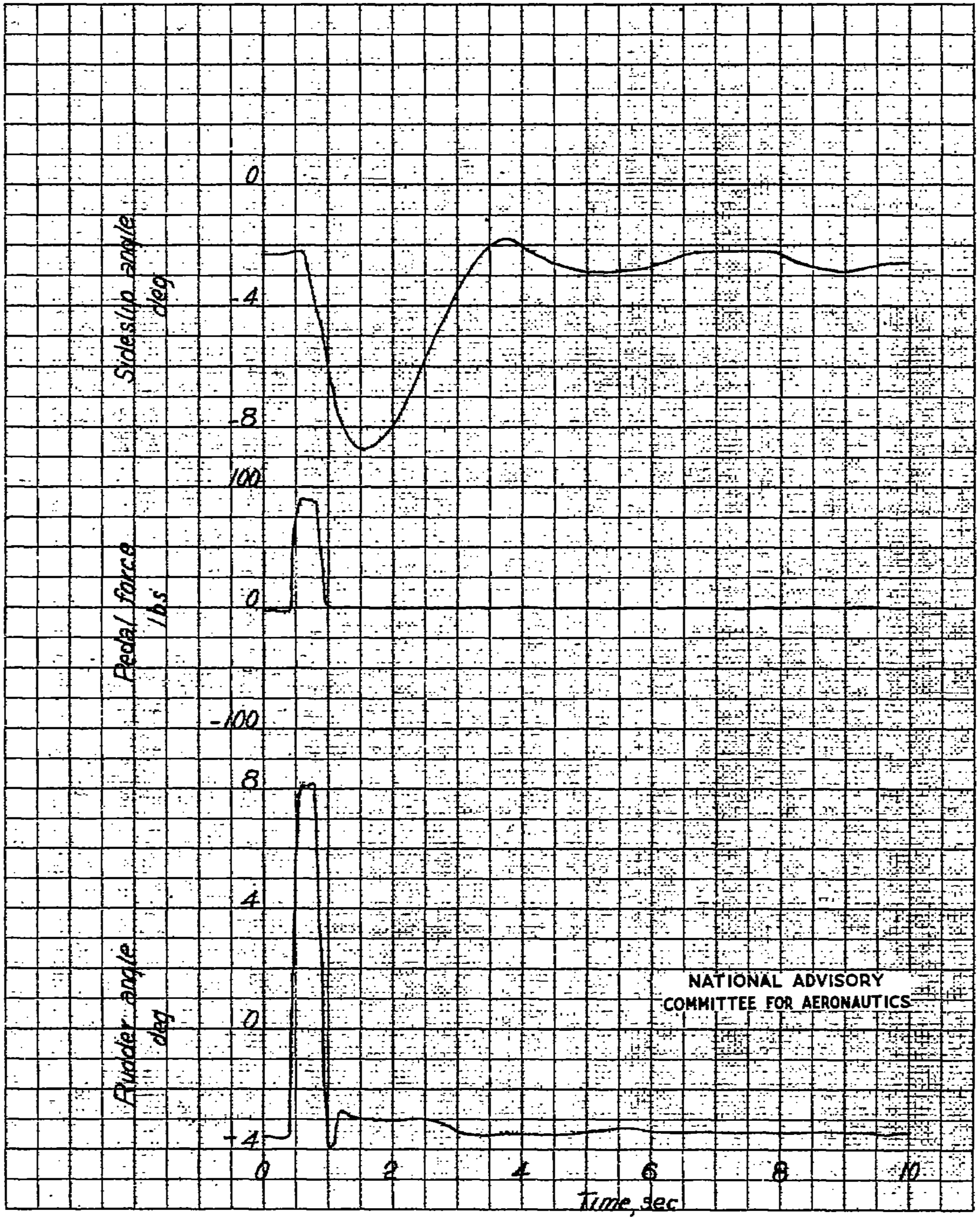

Figure 17.- A typical right rudder kick at 11,000 feet altitude, climbing condition V_{i_s} = 150 miles per hour. P-51D-20-NA airplane with horn balanced rudder having the unbalancing tab locked.

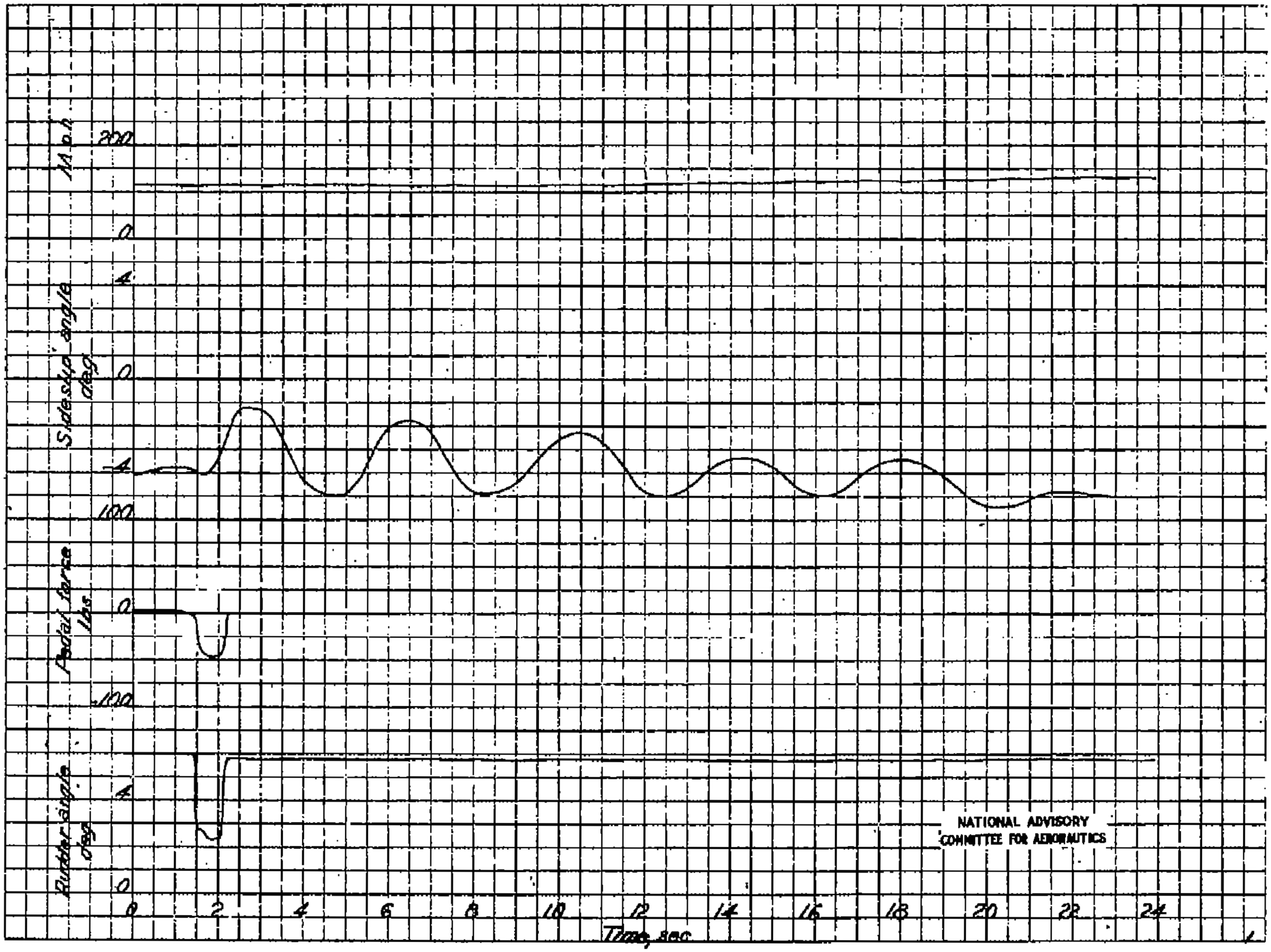

Figure 18.- Rudder kick to left at 25,000 feet altitude, climbing condition V_{i_s} = 130 miles per hour. P-51D-20-NA airplane with horn balanced rudder.

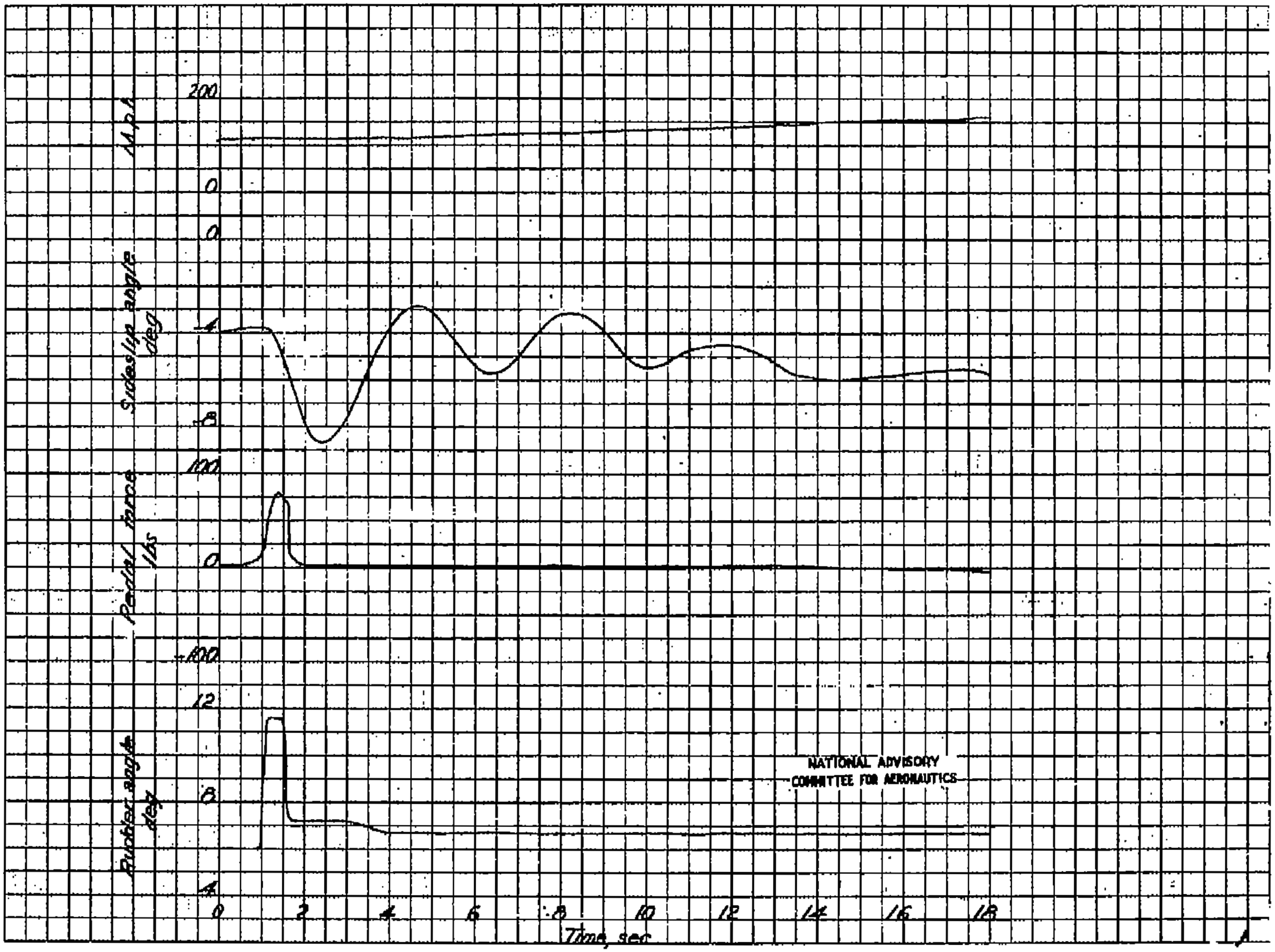

Figure 19.- Rudder kick to right at 25,000 feet altitude, climbing condition V_{i_s} = 130 miles per hour. P-51D-20-NA airplane with horn balanced rudder.