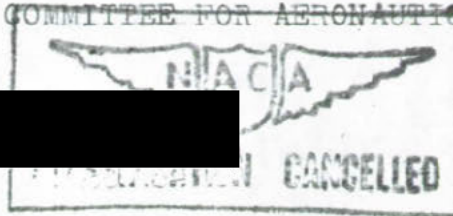


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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command
FLIGHT MEASUREMENTS OF THE DIRECTIONAL STABILITY
AND CONTROL OF A P-51D-5-NA AIRPLANE (AAF NO. 44-13257)

WITH A HIGH-ASPECT-RATIO VERTICAL TAIL

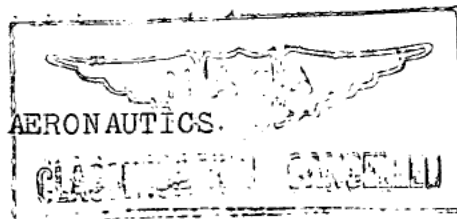
By Walter C. Williams and Herbert H. Hoover

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

MAY 17, 1945



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.



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SUMMARY

Flight measurements were made of the directional stability and control of a P-51D-5 airplane (AAF No. 44-13257), which is at Langley Laboratory for high-speed dive tests, with an extended vertical tail and with the unbalancing tab on the rudder inoperative. These modifications were made before beginning the high-speed dive program because the Langley pilots reported the airplane difficult to control in high-speed dives. Ames Laboratory tests (reference 1) show the directional stability at small angles of sideslip to be low and the change in rudder trim force with speed to be high with the original airplane configuration.

The tests showed that the modifications caused a marked increase in directional stability, rudder fixed and free as measured in steady sideslips. Also, the change in rudder trim force with speed was desirably reduced with the modified tail. The pilots considered the directional stability and control of the P-51D-5 airplane to be satisfactory for the high-speed dive tests with the modified vertical tail.

The expected effect of the fin extension on the vertical-tail load is compared with the results of a previous investigation on the P-63A-1 airplane with a fin extension similar to that used herein. Measurements of the natural frequencies of the vertical tail indicated that its critical flutter speed was reduced approximately 10 percent by the fin extension. The calculated flutter speed, however, is considerably higher than can be obtained with the P-51D-5 airplane.

INTRODUCTION

At the request of the Army Air Forces, Air Technical Service Command, high-speed dive tests will be conducted on a P-51D-5-NA airplane (AAF No. 44-13257). The airplane as received had a dorsal fin and unbalancing tab on the rudder. These items were incorporated by the North American Aviation Corporation as a field modification to reduce the sideslip which could be obtained at high speeds. These modifications, however, did not increase the directional stability for small angles of sideslip. Ames Laboratory tests of the airplane in this configuration (reference 1) showed that the directional stability at small angles of sideslip was low and that the change in rudder trim force with speed was quite high. Langley pilots reported that these shortcomings made the airplane difficult to control in high-speed flight. It was decided, therefore, to modify the airplane in an attempt to overcome these difficulties before proceeding with the dive test program. The modifications made consisted of (1) a fin extension which added 2.15 square feet area and $13\frac{1}{4}$ inches height to the vertical tail and (2) a change in the rudder tab from the unbalancing arrangement to a plain trim tab. These changes were incorporated while the airplane was being instrumented for the first phase of the dive tests. During the initial calibration flights for the dive test program, brief tests were made to determine the directional stability and control of the P-51D airplane with the aforementioned modifications. This paper presents the results of these tests.

This test program was conducted at the Langley Laboratory of the NACA.

AIRPLANE

The P-51D-5-NA airplane is a single-place, fighter-type, low-wing monoplane. A three-view drawing of the airplane with the fin modification is given in figure 1. Side views of the P-51D in the original configuration and with the extended fin are given in figures 2 and 3, respectively. Figure 4 is a photograph showing a P-51D-5 with the production vertical tail in comparison with the

extended vertical tail on the subject airplane. A sketch comparing the production and modified fin is shown in figure 5. It should be noted that the rudder area was reduced slightly with the modified tail, since the cap was removed from the rudder so that faired lines would be obtained between the rudder and fin extension. The fin extension added approximately 2.15 square feet area and $13\frac{1}{4}$ inches height to the vertical tail. The weight of this fin extension was approximately 5 pounds. In addition the rudder tab was changed from an unbalancing arrangement to a plain trim tab.

Pertinent details and dimensions of the P-51D-5-NA airplane are as follows:

Engine	Packard V-1650-7
Rating:	
Take-off (61 in. Hg, 3000 rpm), hp	1500
Normal (46 in. Hg, 2700 rpm)(sea level), hp	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	8524
Center-of-gravity position (wheels down),	
percent M.A.C.	26.26
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° 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
Rudder unbalancing tab ratio,	
approximate	{ 0.6:1 right 0.4:1 left

INSTRUMENTATION

Standard NACA photographically recording instruments were used to measure rudder position, rudder pedal force, sideslip angle, and airspeed. The yaw vane for use with the yaw-angle recorder was mounted 1 chord length ahead of the left wing tip. Airspeed was measured using a Kollsman high-speed-type pitot-static head mounted 1 chord length ahead of the right wing tip. At the time of the present tests, this installation had not been calibrated for position error but it is felt that this error will be of the order of ± 2 percent q_c . Indicated airspeed as used herein is service indicated airspeed, V_{is} , defined by the formula:

$$V_{is} = 45.08 f_o \sqrt{q_c}$$

where

f_o compressibility correction at sea level

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

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 approximately 10,000 and 25,000 feet altitude of the P-51D-5-NA airplane with the vertical-tail extension and without the unbalancing tab. All measurements were made with the airplane in the climbing condition, that is, flaps and gear up with normal-rated power (46 in. Hg and 2700 rpm). Ames Laboratory tests (reference 1) of this same P-51D-5 airplane in its original configuration (dorsal fin and unbalancing tab) furnish comparative data at low altitude for determining the effects of the modifications tested in the present investigation. In addition to the differences in the airplane configuration noted heretofore, the rudder on the P-51D-5 when tested at Ames was fabric-covered while for the present tests it was metal-covered.

The directional stability in sideslips was determined by measuring the rudder deflection, rudder force, and sideslip angle as the rudder was slowly deflected at a given speed. Measurements were made at approximately 103, 198, and 347 miles per hour indicated airspeed at 10,000 feet altitude and at approximately 100, 246, and 347 miles per hour at approximately 25,000 feet altitude. The data obtained at the lower altitude are given in figures 6, 7, and 8 where the rudder position and rudder pedal force are plotted as functions of sideslip angle. Similar plots for the data obtained at the higher altitude are given in figures 9, 10, and 11. The data obtained by the Ames Laboratory with the airplane in its original configuration are shown in figures 6, 7, and 8. The rudder deflections measured in the Langley tests were referenced to the chord line of the fin which is offset 1° to the left. (See fig. 1.) The rudder deflections measured in the Ames tests were referenced to the fuselage center line (reference 1) but for the present report were corrected to degrees from the fin chord line. Comparison of the data on figures 6 to 8 for the two vertical-tail configurations shows that the Langley modifications considerably increased the directional stability of the P-51D airplane. This improvement can be readily seen by comparing values of $d\delta_r/d\beta$ for small angles of sideslip. These values for the original tail are 0.5 at 100 miles per hour and 0.35 at 347 miles per hour. Comparable values for the modified vertical tail are 0.89 and 1.1, respectively. Some of the increase in $d\delta_r/d\beta$ can be attributed to removal of the unbalancing tab which caused a reduction in rudder power. The rudder pedal forces in sideslips are higher with the modified tail and also more nearly linear. Pedal forces in maneuvers, however, would be reduced. Comparing the low altitude data with that obtained at high altitude shows that increasing the test altitude had a destabilizing effect. The value of $d\delta_r/d\beta$ for small sideslip angles at 347 miles per hour indicated at 25,000 feet (Mach number approximately 0.72) is 0.97 compared to 1.1 at 10,000 feet (Mach number approximately 0.54).

The change in rudder force and position required to trim with the wings level through the speed range was determined by measuring the rudder force and rudder position as the speed was slowly changed from the stall to a Mach number of 0.75 at low and high altitude. In the low-altitude tests, the run was begun at 14,000 feet with recovery at 8000 feet. An altitude range from 30,000 to 21,000 feet was covered in the high-altitude tests. The data obtained are shown in figures 12 and 13 where the rudder position and rudder pedal force are plotted as functions of service indicated airspeed. As with the sideslip data, Ames Laboratory data for the original vertical tail are shown on the figure presenting the low-altitude data (fig. 12). It can be seen on figure 12 that the modified vertical tail appreciably reduced the rudder trim-force change with speed. It should be noted that the airplane was trimmed at a lower speed with the modified tail. If the airplane had been trimmed at the same speed, the variation of rudder trim-force with speed would have been less since trimming at a higher speed involves a change in trim-tab setting, the effect of which increases with increasing speed. This means that trimming the airplane with the modified tail at a higher speed than that shown on figure 12 would have required slightly more right pedal force at low speeds and considerably less left pedal force at high speeds. The rudder trim-force characteristics with the enlarged tail on the P-51D-5 airplane compare very closely to the rudder trim-force characteristics of the XP-51 airplane (reference 2). This latter airplane had one of the lowest changes in rudder trim force with speed of the fighter-type airplanes tested at the Langley Laboratory. The rudder trim characteristics at high altitude (fig. 13) were similar to those obtained at low altitudes.

The pilot commented that the directional stability and control of the P-51D-5 airplane was greatly improved with the modified vertical tail. He was particularly impressed with the improvement in the directional control in steady dives at high speeds.

Whenever modifications are made to an airplane involving increases in tail size, the question arises as to changes in tail loads caused by the increased area. Using the arbitrary ANC specifications based on a unit loading, the tail loads will, of course, increase with increases in vertical-tail size. A more realistic approach, however, can be used in determining vertical-

tail loads. In this analysis, the load imposed on the vertical tail during an abrupt aileron roll with the rudder held fixed in accelerated flight is considered (reference 2). Using the method outlined in reference 2, it can be shown that the tail loads will decrease somewhat with increase in the vertical-tail size because the increased directional stability does not allow the airplane to sideslip as far with the larger tail for a given aileron deflection. Calculations using flight-determined stability characteristics for the Bell P-63A-1 airplane with an enlarged vertical tail showed that the total vertical-tail load was decreased with the enlarged tail because of the increased directional stability (reference 3). Similarly the vertical-tail load per degree rudder will be decreased because of the increased directional stability.

It was felt that a structure such as used in the present modification, that is, a relatively uniform mass supported only along the forward third of the chord might be susceptible to flutter. An experimental check of the flutter characteristics of P-51D vertical tails with and without the fin extension, therefore, was made by personnel of the Langley Physical Research Division. This investigation consisted of vibrating the two vertical-tail arrangements to determine the natural frequencies. The results of these tests showed that the critical flutter speed will be approximately 10 percent lower with the fin extension installed. Because of the relatively high frequencies measured with either tail, the flutter speed is in the range of high Mach numbers where no accurate estimates of the flutter speed are possible; the calculated critical flutter speeds in either case, however, are considerably higher than the speed that can be obtained with the P-51D-5 airplane.

CONCLUSIONS

The investigation of the P-51D-5 airplane with the extended vertical tail and without the unbalancing tab showed the following:

1. The modifications to the vertical tail caused a marked increase in the directional stability rudder fixed and free in steady sideslips.

2. The change in rudder trim force with speed was desirably reduced with the modified tail.

3. The pilot considered the directional stability and control of the P-51D-5 airplane with the modified vertical tail to be satisfactory for the high-speed dive tests.

4. It is believed on the basis of previous tests and calculations that a fin extension such as used herein will not cause higher vertical-tail loads in critical maneuvering conditions.

5. Measurements of the natural frequencies of vibration of the vertical tail indicated that its critical flutter speed was reduced approximately 10 percent by the fin extension. The calculated flutter speed, however, is considerably higher than can be obtained with the P-51D-5 airplane.

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2. Gilruth, Robert R.: Analysis of Vertical-Tail Loads in Rolling Pull-Out Maneuvers. NACA CB No. L4H14, 1944.
3. Johnson, Harold I.: Estimates of the Vertical-Tail Loads of a Bell P-63A-1 Airplane (AAF No. 42-68889) in Accelerated Rolling Maneuvers Based on Flight Tests with Two Vertical-Tail Arrangements. NACA MR No. L4K30a, Army Air Forces, 1944.

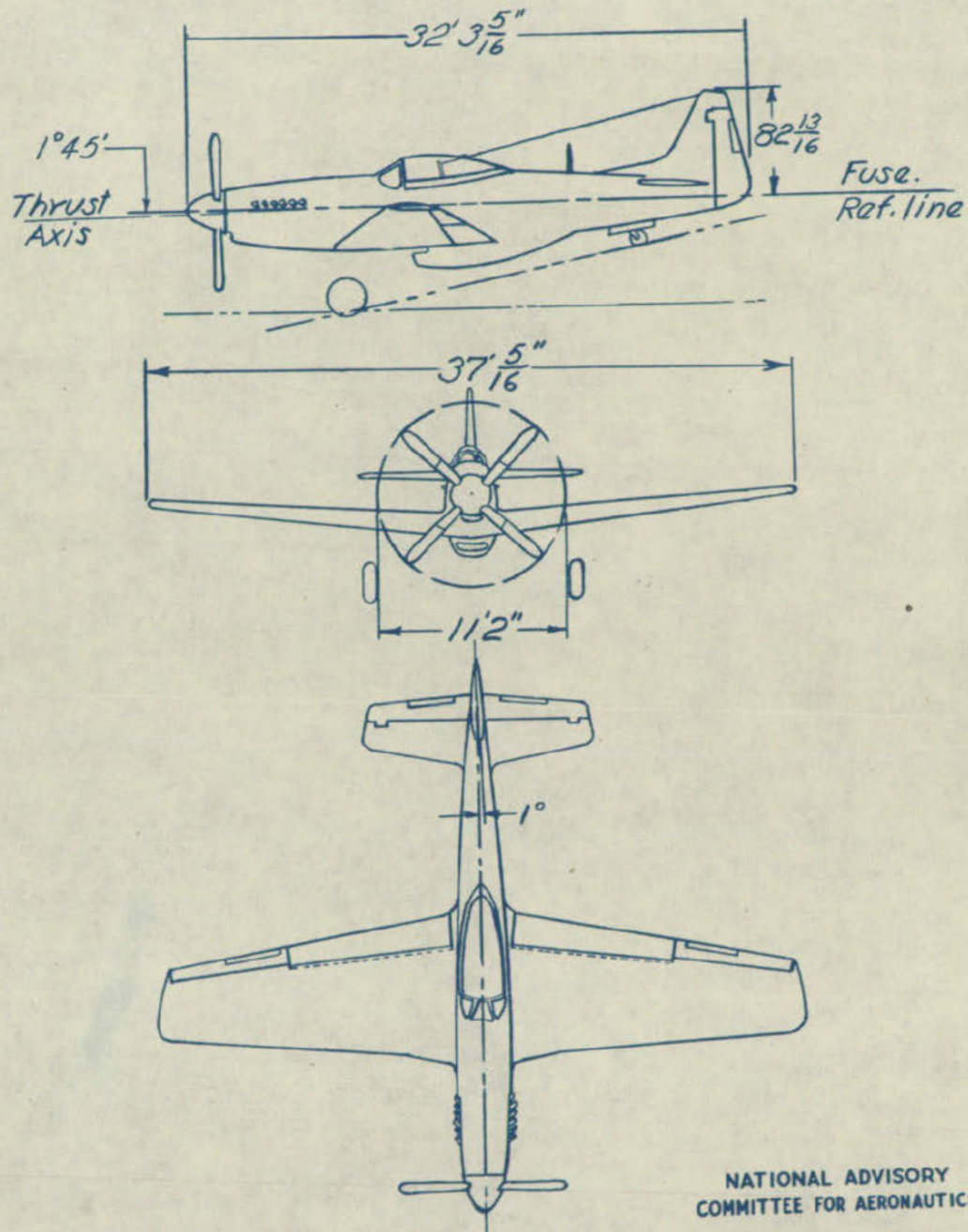


Figure 1. - Three-view layout of P-51D-5-NA airplane with modified vertical tail.

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Figure 2.- Side view of P-51D-5-NA (AAF No. 44-13257) with original vertical tail.

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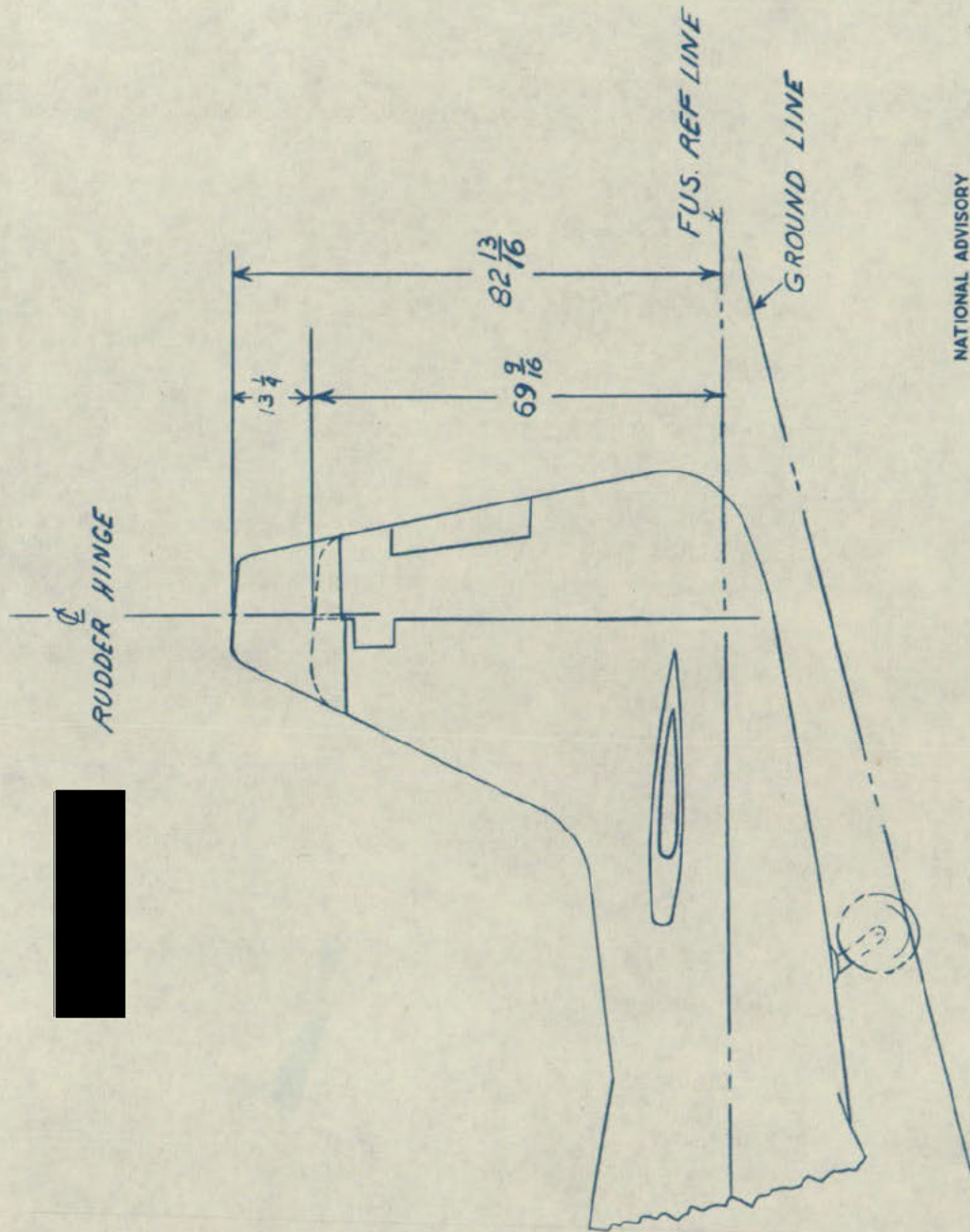
Figure 3.- Side view of P-51D-5-NA airplane, AAF No. 44-13257 with NACA extended vertical tail.

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Figure 4.- Comparison of a P-51D-5-NA airplane with a production vertical tail, and P-51D-5-NA, AAF No. 44-13257 with NACA extended vertical tail.

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Figure 5. - Sketch of P-51D-5-NA tail group showing
NACA modification.

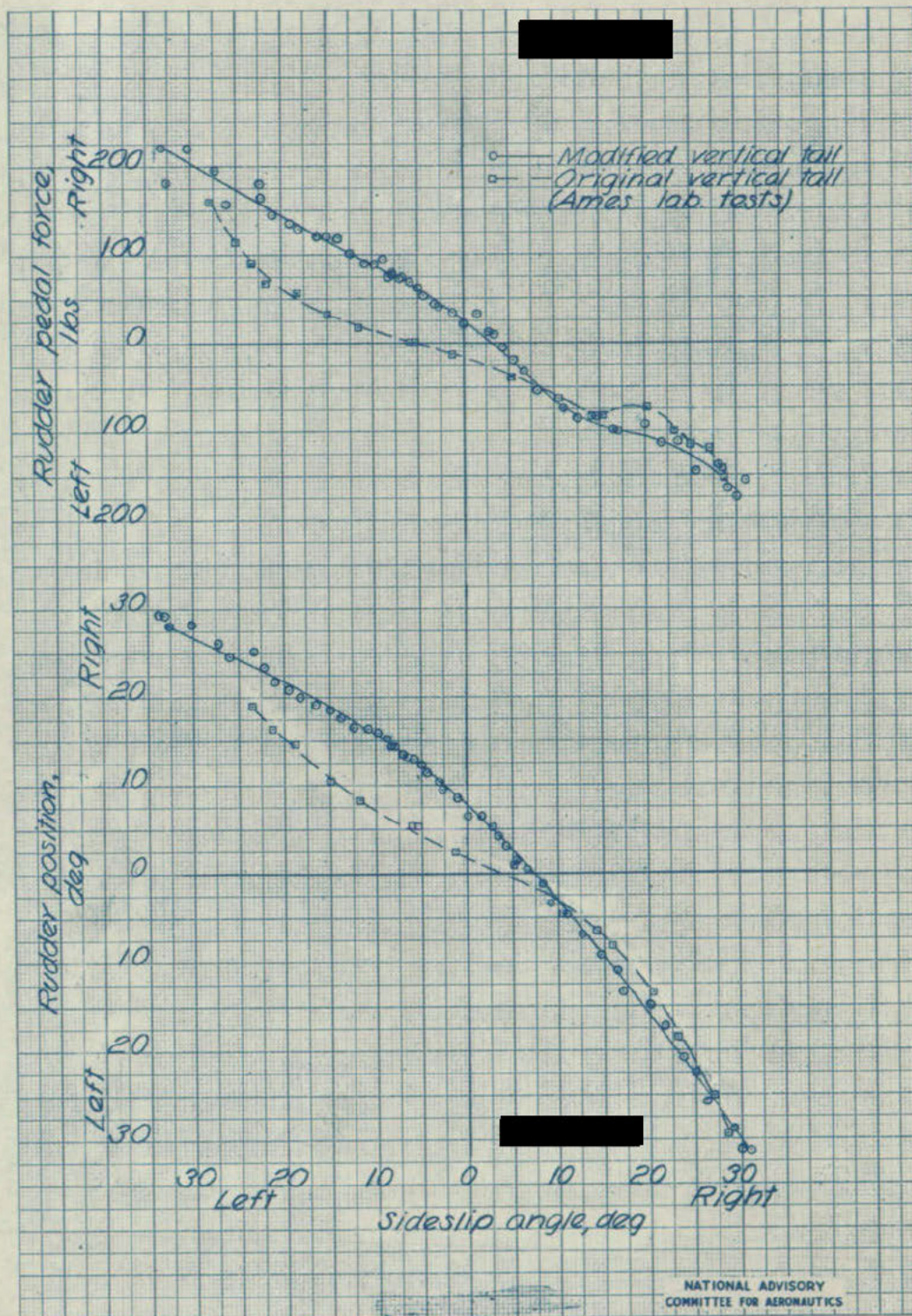


Figure 6. - Steady sideslip characteristics at 10,000 feet altitude, climbing condition, $V_{1g} = 103$ miles per hour. P-51D-5-NA airplane with original vertical tail and NACA modified vertical tail.

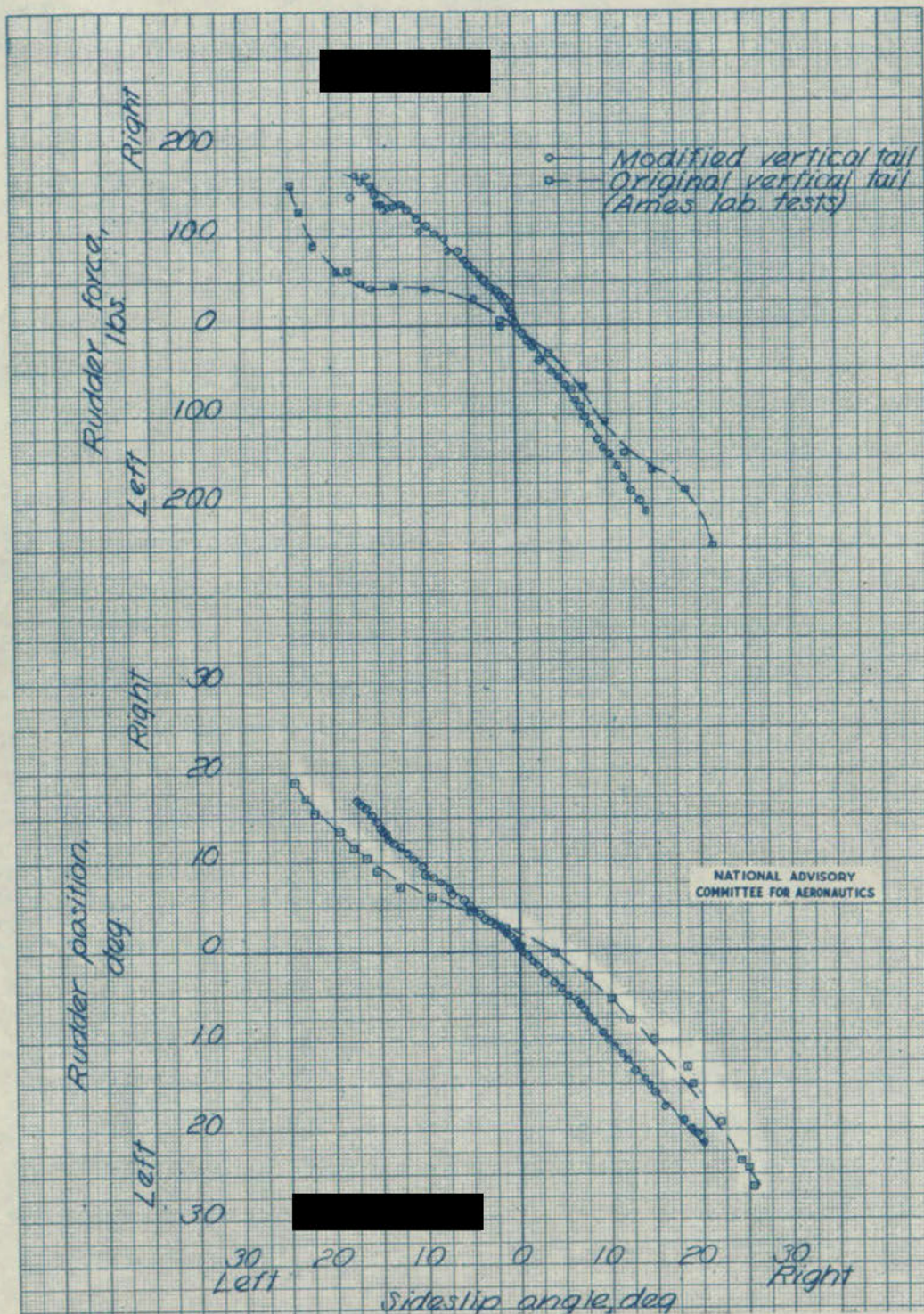


Figure 7. - Steady sideslip characteristics at 10,000 feet altitude, climbing condition, $V_{1S} = 198$ miles per hour. P-51D-5-NA with original vertical tail and NACA modified vertical tail.

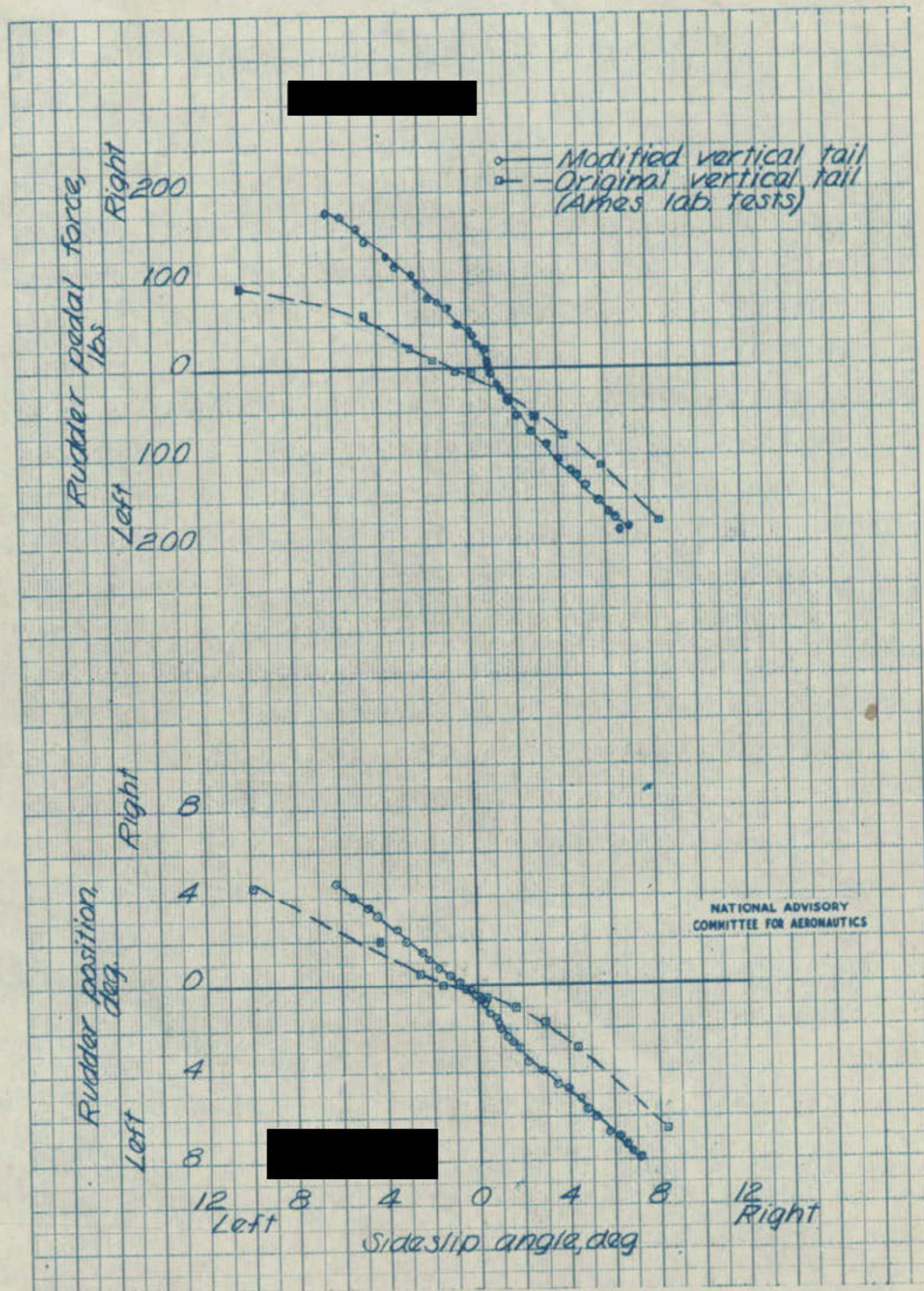


Figure 6. - Steady sideslip characteristics at 10,000 feet altitude, climbing condition, $V_{1g} = 347$ miles per hour. P-51D-5-NA with original vertical tail and NACA modified vertical tail

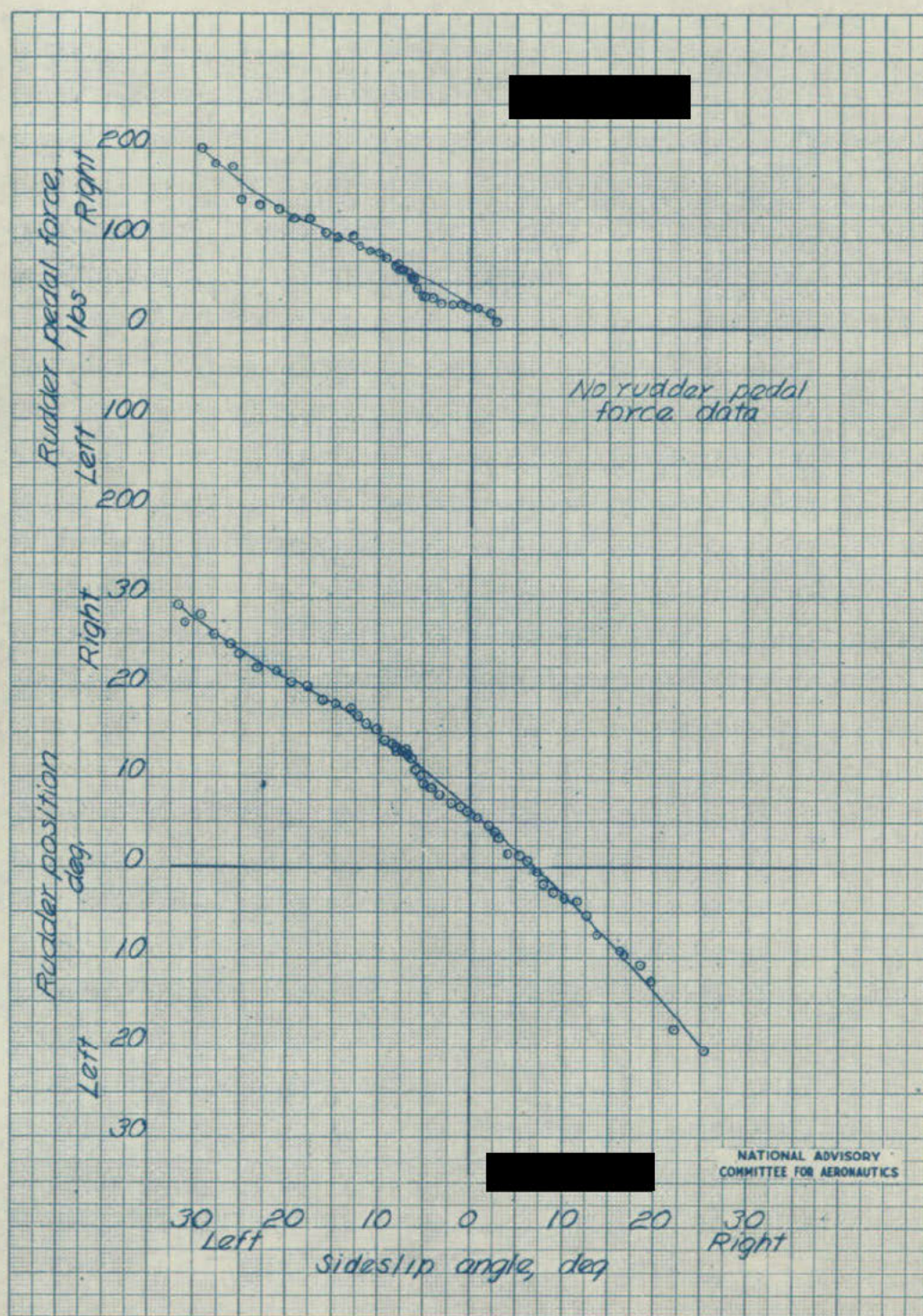


Figure 9. - Steady sideslip characteristics at 25,000 feet, climbing condition, V_{10} = 100 miles per hour. P-51D-5-NA airplane with NACA modified vertical tail.

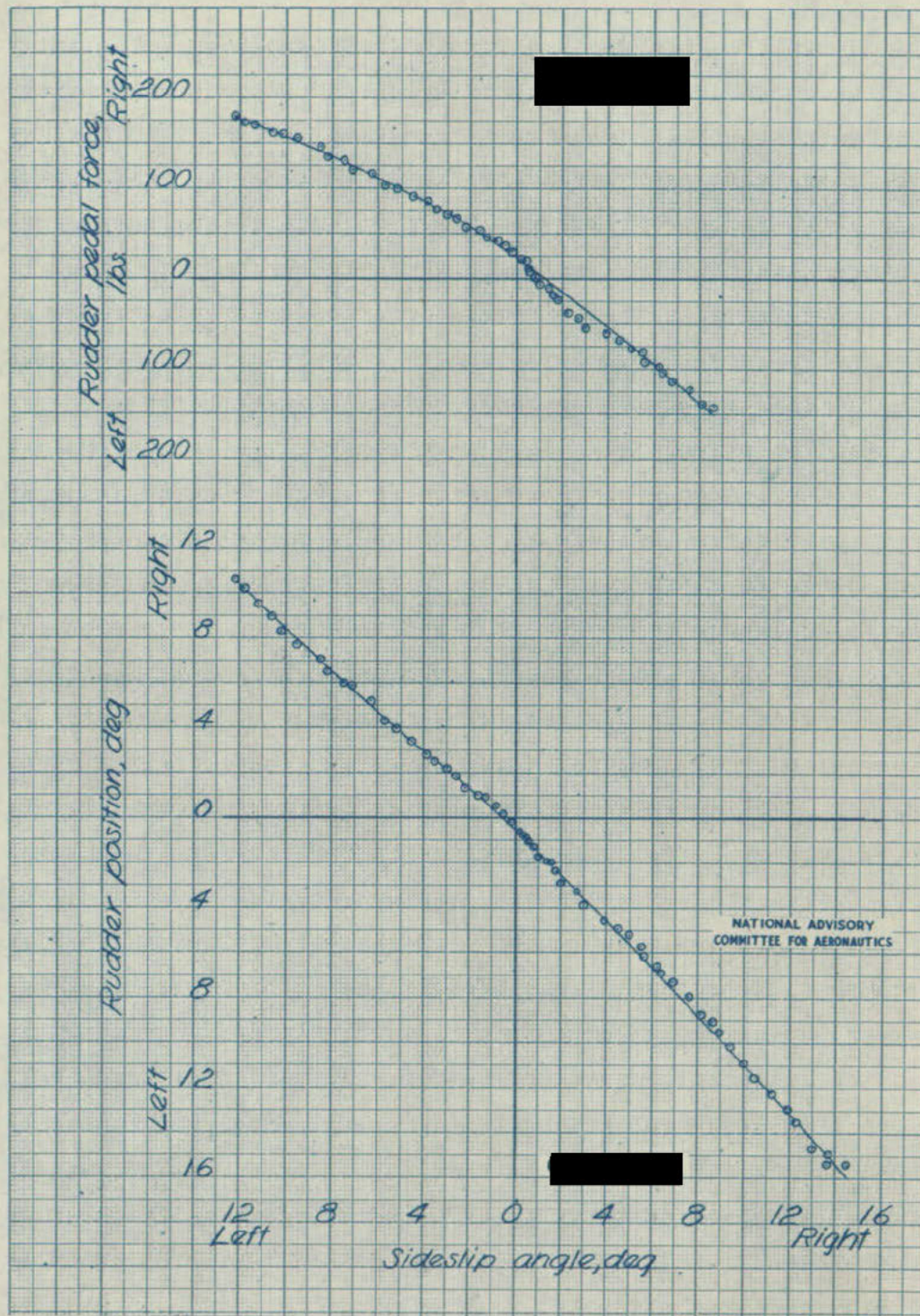


Figure 10. - Steady sideslip characteristics at 25,000 feet altitude, climbing condition, $V_{10} = 246$ miles per hour. P-51D-5-NA airplane with NACA modified vertical tail.

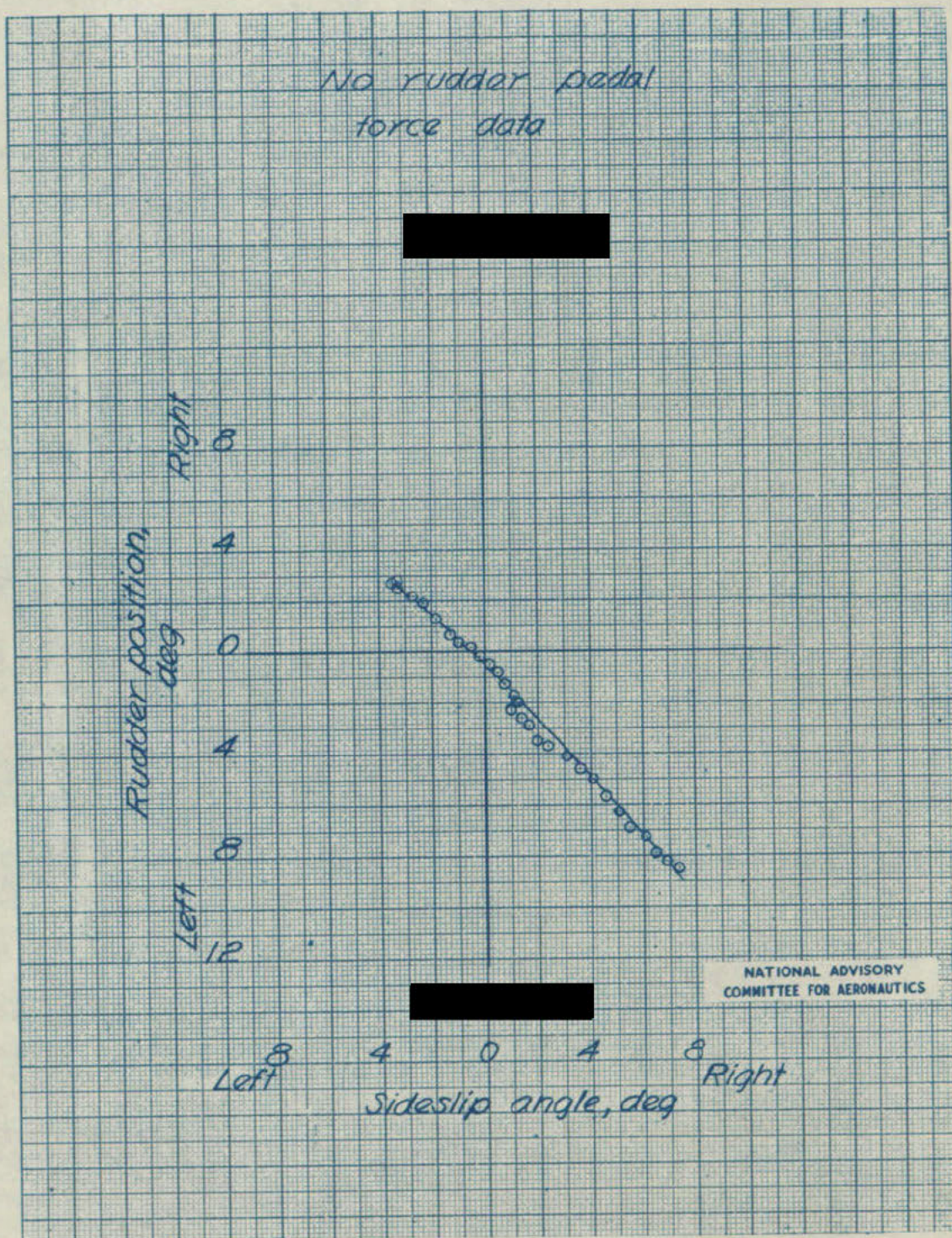


Figure 11. - Steady sideslip characteristics at 25,000 feet altitude, climbing condition, $V_{is} = 347$ miles per hour, Mach number approximately 0.72. P-51D-5-NA airplane with NACA modified vertical tail.

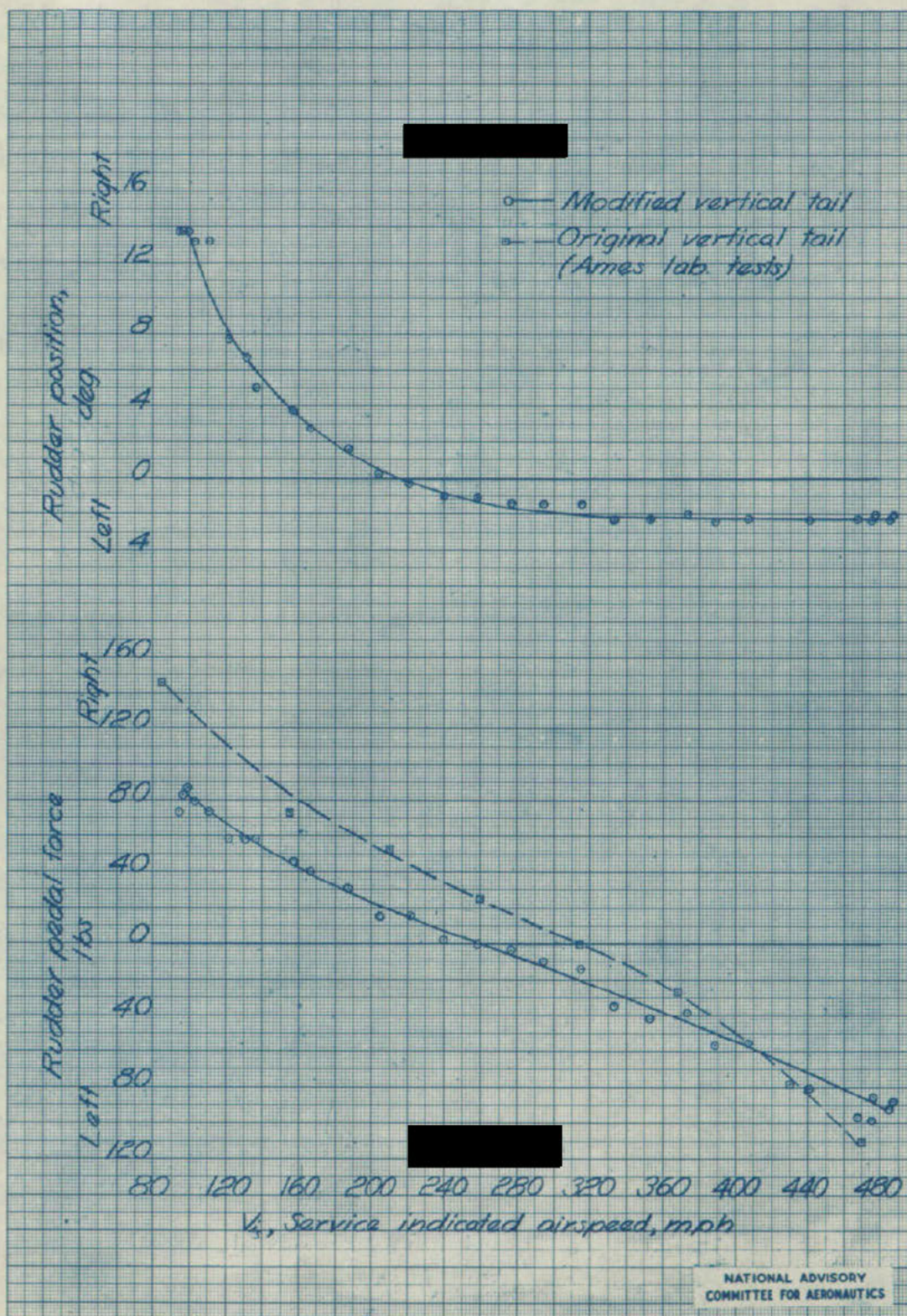


Figure 12. - Rudder trim characteristics in diving through the speed range from 14,000 to 8,000 feet altitude. P-51D-5-NA airplane with original vertical tail and NACA modified tail.

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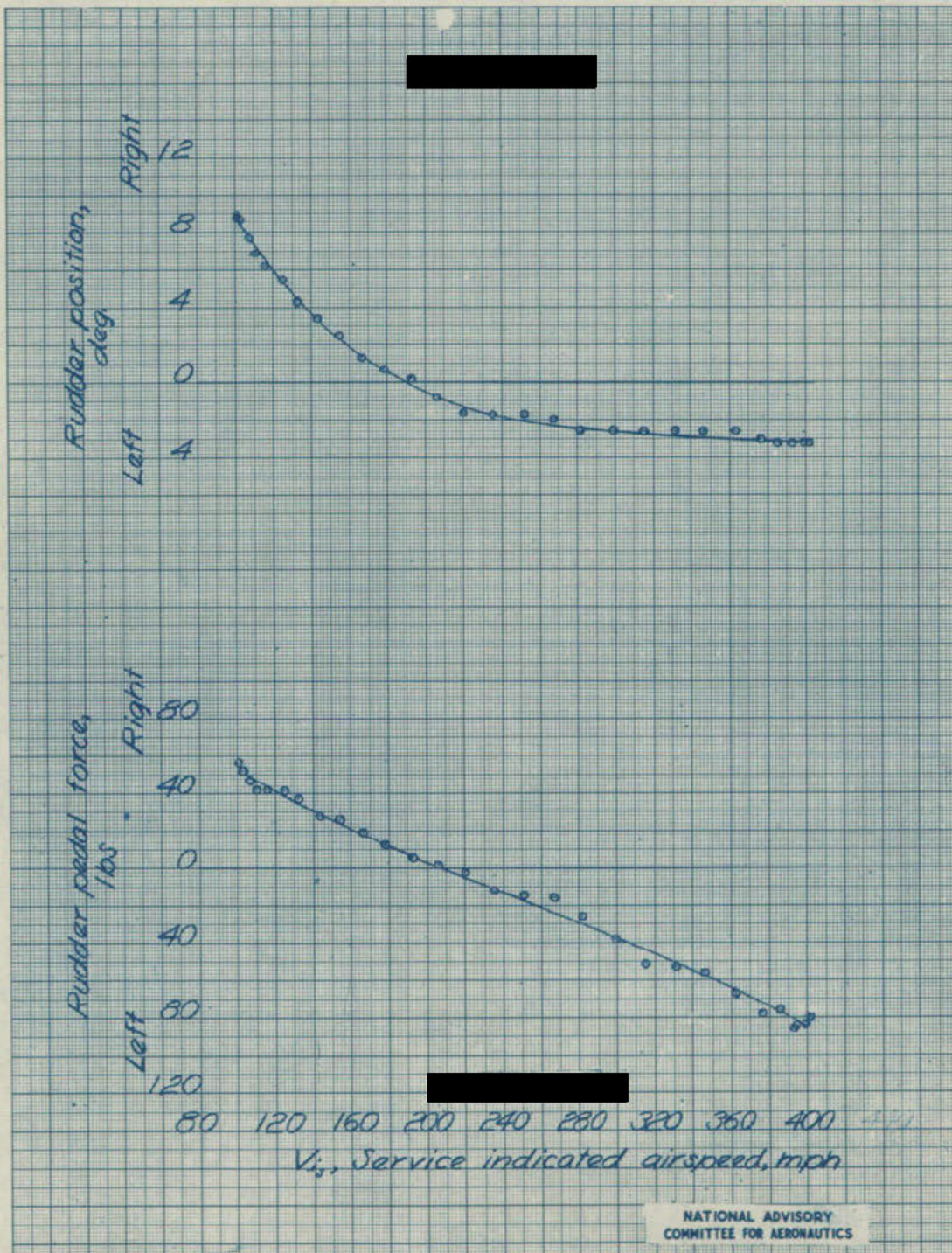


Figure 13. - Rudder trim characteristics in diving through the speed range from 30,000 to 21,000 feet altitude. P-51D-5-NA with NACA modified vertical tail.