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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE CONFIDENTIAL REPORT #222

STUDY OF TURNING PERFORMANCE OF A FIGHTER-TYPE AIRPLANE PARTICULARLY AS AFFECTED BY FLAPS AND INCREASED SUPERCHARGING

By J. W. Wetmore
Langley Memorial Aeronautical Laboratory

SR-222

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June 1942

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Baker

ERRATA

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Page 6, second unnumbered equation:

$$t = \frac{\beta}{57.3}\left(\frac{\sqrt{\sigma R}}{1.47\ V_i}\right) \text{ should read: } t = \frac{\beta}{57.3}\left(\frac{\sqrt{\sigma}\ R}{1.47\ V_i}\right)$$

fourth unnumbered equation and line following:

$\sqrt{\sigma t}$ should be $\sqrt{\sigma}\ t$

Page 7, first equation:

$$\left(\frac{T_e - D_t}{W}\right) = l_s\left[\left(\frac{T_e - D_l}{W}\right)\frac{1}{l_s} = \Delta\gamma\right] = l_s\ (\gamma - \Delta\gamma)$$

should read:

$$\left(\frac{T_e - D_t}{W}\right) = l_s\left[\left(\frac{T_e - D_l}{W}\right)\frac{1}{l_s} - \Delta\gamma\right] = l_s\ (\gamma - \Delta\gamma)$$

In line 8 and last equation:

$\sqrt{\sigma t}$ should be $\sqrt{\sigma}\ t$

Page 8, lines 1 and 3; and page 13, lines 1, 5, 18, and 22:

$\sqrt{\sigma t}$ should be $\sqrt{\sigma}\ t$

Page 21, table I, column 1:

Under "Flap", opposite fifth and sixth groups:

Insert "Split".

VSA NOTE: Pg 8 Second equation probably should [illegible]
[illegible]

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STUDY OF TURNING PERFORMANCE OF A FIGHTER-TYPE AIRPLANE PARTICULARLY AS AFFECTED BY FLAPS AND INCREASED SUPERCHARGING

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SUMMARY

Results of a study to determine the effects on turning performance due to various assumed modifications to a typical Naval fighter airplane are presented. The modifications considered included flaps of various types, both part and full span, increased supercharging, and increased wing loading.

The calculations indicated that near the low-speed end of the speed range, the turning performance, as defined by steady level turns at a given speed, would be improved to some extent by any of the flaps considered at altitudes up to about 25,000 feet. (If turning is not restricted to the conditions of no loss of speed or altitude, more rapid turning can, of course, be accomplished with the aid of flaps, regardless of altitude.) Fowler flaps and NACA slotted flaps appeared somewhat superior to split or perforated split flaps for maneuvering purposes, particularly if the flap position is not adjustable. Similarly, better turning performance should be realized with full-span than with part-span flaps. Turning performance over the lower half of the speed range would probably not be materially improved at any altitude by increased supercharging of the engine unless the propeller were redesigned to absorb the added power more effectively; with a suitable propeller the turning performance at high altitudes could probably be greatly improved with increased supercharging. A reduction in wing area with the aspect ratio held constant would result in impairment of turning performance over practically the entire speed range at all altitudes.

INTRODUCTION

In accordance with the request of the Bureau of Aeronautics, Navy Department, an analysis has been made to determine the extent to which the turning performance of a fighter-type airplane at various altitudes might be expected to improve through the use of flaps and by increasing the critical altitude of the engine with a more effective supercharger. Four types of flap were considered; namely, NACA slotted, Fowler, split, and perforated split flaps. For the slotted and split types both part- and full-span installations were investigated. Estimation of the effectiveness of improved supercharging was based on a comparison of the calculated turning characteristics of the airplane when equipped with a two-stage gear-driven supercharger giving a critical altitude of 19,000 feet and when equipped with a turbo supercharger, which increased the critical altitude to 25,000 feet. Some consideration was also given to the effects on turning performance due to varying propeller diameter and wing loading.

There is apparently no simple and entirely adequate criterion whereby relative turning performance may be judged. The minimum attainable radius and the minimum time required to turn through a given angle in steady full-throttle turns have been used as criterions to some extent but, in general, this procedure does not appear satisfactory particularly, for combat airplanes. In the first place, it would be necessary to decide whether a short time of turn or a small radius of turn is the more desirable because, in comparing different airplanes for which the minimum values of radius or time to turn occur at different speeds, it is quite possible for one airplane to turn with a smaller radius and yet require a longer time to turn than another. Furthermore, an airplane that is capable of turning with a smaller radius than another by virtue of its ability to fly at a lower speed may give a larger radius of turn if both airplanes are flown at the same speed. It appears desirable, therefore, to compare the turning performance of different airplanes or of a given airplane with various modifications at given speeds throughout the level-flight speed range. In this case the choice of time of turn or radius of turn is unimportant because at a given speed one is directly proportional to the other.

The results of the present analysis are given in charts generally similar to those used in reference 1 from which the turning performance at any speed for any of the conditions investigated can be readily estimated. In addition, figures are provided that show the turning performance for particular conditions to facilitate comparison.

METHOD

Symbols.- The symbols used in the derivations and in presenting the results are defined as follows:

T_e	effective propeller thrust, pounds
bhp	brake horsepower
D	drag of airplane, pounds
C_L	lift coefficient
C_D	drag coefficient
C_{D_o}	profile-drag coefficient
C_{D_i}	induced-drag coefficient
$C_{m_{a.c.}}$	pitching-moment about aerodynamic center
f	total equivalent parasite area of airplane, square feet
f_w	equivalent parasite area of wing, square feet
S	wing area
W	gross weight of airplane, pounds
l_w	wing loading, pounds per square foot
l_s	effective span loading, pounds per square foot $\frac{W}{(e_1 b)^2}$
n	load factor or normal acceleration, g
c	chord
b	span
δ_f	flap deflection
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
V	true airspeed, feet per second
V_i	correct indicated airspeed, miles per hour
R	radius of turn, feet

g acceleration due to gravity

ρ mass density of air

σ ratio of air density at altitude to air density at sea level

t time to turn through a given angle, seconds

h altitude

V_s indicated stalling speed, miles per hour

ϕ angle of bank, degrees

β angle through which airplane turns, degrees

$$\gamma = \left(\frac{T_e - D_l}{W}\right)\frac{1}{l_s}$$

$$\Delta\gamma = \left(\frac{D_t - D_l}{W}\right)\frac{1}{l_s} = \frac{\Delta \text{Thrust}_t \times e_t^{2}\,\overline{AR}}{W/S}$$

Subscripts:

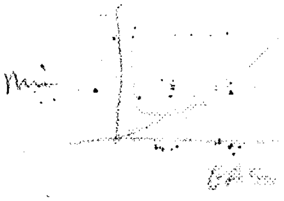
f flap

w wing

l straight flight

t turning flight

o sea level



Development of turning-performance charts.- The method of calculating the turning performance and of presenting the results is, in principle, the same as that used in reference 1. The turning-performance charts were modified somewhat to a more general form to permit comparison of different airplanes or modifications of a given airplane on a single chart.

Use of this method depends on the validity of the following assumptions:

1. The turn is made without sideslip.

2. The total drag coefficient of the airplane varies as the square of the lift coefficient

3. The propeller thrust at a given speed is the same in a turn as in level flight

From these assumptions it follows that the drag of the airplane in a turn may be expressed as

$$D_t = fq + \frac{n^2 W \, l_s}{\pi q}$$

The increase in drag in the turn over that in level flight at the same speed is

$$\Delta D = W \frac{l_s}{\pi q} (n^2 - 1)$$

or

$$\Delta\gamma = \frac{\Delta D}{W} \frac{1}{l_s} = \frac{n^2 - 1}{\pi q} \qquad (1)$$

The radius of turn is given by the relation

$$R = \frac{2q}{\rho g \sqrt{n^2 - 1}}$$

so that

$$\Delta\gamma = \frac{4q}{\pi (\rho g R)^2} \qquad (2)$$

In terms of indicated airspeed V_i in miles per hour, equations (1) and (2) become

$$\Delta\gamma = \frac{n^2 - 1}{\frac{\pi \rho_o}{2} (1.47 V_i)^2} = 124 \frac{n^2 - 1}{V_i^2} \qquad (1a)$$

and

$$\Delta\gamma = \frac{2(1.47V_i)^2}{\pi\rho_0 g^2(\sigma R)^2} = 0.56\,\frac{V_i^{\,2}}{(\sigma R)^2} \qquad (2a)$$

From equations (1a) and (2a) a chart can be constructed by plotting one series of curves of $\Delta\gamma$ against V_i with n as the parameter and another series with σR as the parameter. (See figs. 3 to 11.) In addition, the angles of bank corresponding to the n curves can be determined from the relation

$$\cos\phi = \frac{1}{n}$$

and can be given together with the n values. In a steady turn, the time to turn through a given angle β in degrees is

$$t = \frac{\beta}{57.3}\left(\frac{\sqrt{\sigma R}}{1.47\;V_i}\right)$$

which becomes, upon substitution of R from equation (2a)

$$t = \frac{\beta\,(\sqrt{0.56})}{1.47\,(57.3)(\sqrt{\sigma\Delta\gamma})}$$

or

$$\sqrt{\sigma}\,t = \frac{0.0089\beta}{\sqrt{\Delta\gamma}}$$

so that $\sqrt{\sigma}\,t$ depends only on $\Delta\gamma$ and a scale of $\sqrt{\sigma}\,t$ can be provided on the chart along the $\Delta\gamma$ axis.

The excess thrust available in a turn is

$$(T_e - D_t) = (T_e - D_l) - \Delta D$$

or

$\Delta\gamma = \left(\frac{D_t - D_l}{W}\right)\frac{1}{l_s}$ & $D_t - D_l = \Delta D$

$$\left(\frac{T_e - D_t}{W}\right) = l_s \left[\left(\frac{T_e - D_l}{W}\right)\frac{1}{l_s} - \Delta\gamma\right] = l_s\ (\gamma - \Delta\gamma)$$

For a steady turn at constant altitude where the available thrust is fully utilized.

$$\Delta\gamma = \gamma$$

Thus, if a plot of γ against V_i for any airplane under any condition is superimposed on the chart, the values of σR, $\sqrt{\sigma}\,t$, and n (or ϕ) on the chart corresponding to any point on the γ curve represent the best turn that can be accomplished at the corresponding speed without loss of speed or altitude, provided, of course, that the turn is not limited by stalling.

For a turn such that the value of $\Delta\gamma$ is above the γ curve, the airplane will lose speed or altitude or both during the turn and, conversely, if the value of $\Delta\gamma$ falls below the γ curve, the airplane may gain speed or altitude in the turn. In the case of a turn at constant altitude, the acceleration or deceleration can be determined from the relation

$$\frac{dV}{dt} = g l_s\ (\gamma - \Delta\gamma)$$

For a turn at constant speed but varying altitude, the rate of ascent or descent in feet per second is given by

$$\frac{dh}{dt} = \frac{1.47 V_i\ l_s\ (\gamma - \Delta\gamma)}{\sqrt{\sigma}}$$

The change of altitude during a turn through a given angle is then

$$\Delta h = \frac{1.47 V_i\ l_s\ (\gamma - \Delta\gamma)(\sqrt{\sigma t})}{\sigma}$$

The values of $\sqrt{\sigma t}$, σR, and n corresponding to a given value of $\Delta\gamma$ or, conversely, the values of $\Delta\gamma$ and $\sqrt{\sigma t}$ corresponding to a given value of σR or n at a given speed can be read directly from the chart.

The speed at which an airplane stalls in a turn, if the effects of Reynolds number and slipstream on the maximum lift coefficient are neglected, is given by

$W = C_{L_{max}} \frac{(V_{s_l})^2}{391} S$

$nW = C_{L_{max}} \frac{V_{s_t}^2}{391} S$

$\therefore \sqrt{n} = \frac{V_{s_t}}{V_{s_l}}$

$$\frac{V_{s_t}}{V_{s_l}} = \sqrt{n}$$

or, in terms of $\Delta\gamma$, upon substitution for n from equation (1a), the stall-boundary curve for a given airplane can be plotted on the chart by use of the relation

$$\Delta\gamma = \frac{124}{{V_{s_t}}^2}\left(\frac{V_{s_t}}{V_{s_l}}\right)^2 \quad \times$$

may be V_{st}^2

$\Delta\gamma = \frac{124}{2V_{st}^2}\left(\frac{V_{st}^4}{V_{sl}^4} - 1\right)$ (? MS)

Turns can be made only under conditions represented by the part of the chart lying to the right of the stall-boundary curve. For an airplane equipped with flaps or other lift-increasing device, the stall boundary is moved to the left as the device is applied. The effects of slipstream and variations in Reynolds number were neglected because of the inadequacy of available information on these effects, particularly when flaps are used. The stall-boundary curves as defined, therefore, give stalling speeds that are somewhat too high.

Description of airplane.- A typical naval fighter airplane was used as the subject of the analysis. The pertinent characteristics of the airplane are given in the following table:

Weight, pounds	6800
Wing area, square feet	260
Wing span, feet	38
$\frac{\text{Tip chord}}{\text{Root chord}}$	0.6
$\frac{\text{Tail length}}{\text{Mean wing chord}}$	2.6

Propeller type	3 blade, constant speed
Propeller diameter, feet	9.75
Propeller gear ratio	3:2
Supercharger	2-stage, gear-driven
power rating	sea level to 3500 feet, 1100 bhp at 2550 rpm 4800 feet to 11,000 feet, 1050 bhp at 2550 rpm 12,200 feet to 19,000 feet, 1000 bhp at 2550 rpm
Estimated equivalent parasite area of airplane, less wings, square feet	4.0

The foregoing characteristics will be referred to in the report as normal.

Calculation of thrust.- In the absence of suitable data for the type of propeller actually used on the airplane considered in this analysis, the propeller blades were assumed to be of the Navy type 5868-9. The thrust was computed from data on this type of propeller taken from reference 2 and was corrected for compressiblity effects in accordance with the methods of reference 3. The computations covered the level-flight speed range at each of three altitudes: 11,000, 25,000, and 35,000 feet, both for the geared supercharger with which the airplane is normally equipped and for a turbosupercharger which was assumed to maintain sea-level rated power up to an altitude of 25,000 feet. In addition, the calculations were repeated with the propeller diameter arbitrarily increased from 9.75 feet to 10.75 feet. In all cases it was assumed that all the available power was utilized.

Above the critical altitude of the engine, that is, 19,000 feet with the geared supercharger and 25,000 feet with the turbosupercharger, the power delivered by the engine was assumed to decrease with increasing altitude in accordance with the relation

$$\frac{bhp}{bhp_c} = 1.133\frac{\sigma}{\sigma_c} - 0.133$$

where the subscript c denotes conditions at the critical altitude.

The values of power and engine speed used in the thrust calculations are shown in the following table:

Altitude (ft)	Geared supercharger		Turbo-supercharger	
	bhp	rpm	bhp	rpm
11,000	1050	2550	1100	2550
25,000	790	2550	1100	2550
35,000	505	2550	716	2550

The calculated thrust curves for the various conditions are shown in figure 1.

Determination of lift and drag.- Section lift, drag, and pitching-moment data for the plain wing and for the wing equipped with NACA slotted, Fowler, and split flaps (see fig. 2) were obtained from two-dimensional-flow tests, all made under the same conditions and reported in references 4, 5, and 6. The data used for the perforated split flap arrangement were obtained from unpublished test results on a complete airplane model at relatively low Reynolds number. In lieu of direct use of these data, it was assumed that the ratio of lift increment due to the flaps with perforations to that due to flaps without perforations and similarly the ratio of profile-drag increment due to flaps with perforation to that due to flaps without perforation, as shown by these data (the lift and drag increments were both reduced about 30 percent by the perforations), could be applied to the data used for the plain split flap (reference 6).

The data of the two-dimensional-flow tests were converted to the flow conditions for the actual finite wing by the methods of reference 7. It was assumed that the lift and drag increments caused by the flaps were maintained across the fuselage. Inasmuch as the effective Reynolds number of the afore-mentioned tests was relatively high (3,500,000) and in view of the incompleteness of information on Reynolds number effects for wings with flaps, no corrections for Reynolds number were made. Similarly, since there is little useful knowledge of the effects of slipstream on the lift and drag of wings with flaps, these effects were likewise neglected. Lift coefficients were corrected for tail load by the relation.

$$\Delta C_L = C_{m_{a.c.}} \times \frac{\text{mean chord}}{\text{tail length}}$$

In order to convert the lift and drag characteristics to the form used in the turning-performance equations and charts, total drag coefficients $(C_{D_o} + C_{D_i})$ were plotted against the square of the lift coefficient. In all cases these plots were very nearly the straight lines desired except, possibly, at very small lift coefficients and near maximum lift. The equivalent parasite area of the wing f_w and the effective span loading l_s were determined from the straight lines most nearly representing the actual variations by the relations

$$f_w = C_{D_o} S$$

and

$$l_s = \pi l_w \frac{dC_D}{dC_L^2}$$

where C_{D_o} is the drag coefficient defined by the straight line at zero lift and $\frac{dC_D}{dC_L^2}$ is the slope of the straight line.

The characteristics of the various wing conditions considered in the analysis are given in table I.

The Fowler flap was assumed to be fully extended before angular deflection started.

RESULTS AND DISCUSSION

Presentation of results.- The results of the calculations are presented in figures 3 to 11 in the form of charts from which the turning characteristics of the airplane may be determined for any of the conditions covered in the analysis. Each chart shows γ curves and stall-boundary curves for three flap positions in addition to the no-flap condition at each of three altitudes. Figures 3 to 6 give the results for the normal airplane equipped with part-span flaps of NACA slotted, Fowler, split, and perforated-split type in that order. Figures 7 and 8 are for the normal airplane with full-span NACA slotted and split flaps, respectively. In figure 9 the airplane is modified by replacement of the geared supercharger with the turbosupercharger. Figure 10 is for the case of the turbosupercharger with propeller diameter increased. The last chart, figure 11, shows the effect of reducing wing area. For the cases shown by figures 9, 10, and 11, the airplane was assumed to be equipped with part-span NACA slotted flaps.

In addition to the general turning-performance charts the effects of the various assumed modifications to the airplane are shown by direct comparison, for the case of level steady turns in figures 12 to 15. Figure 16 shows the effect of reducing speed during the turn. In these figures the information is presented for each of three altitudes as the ratio of the minimum radius of level steady turn for the normal conditions with flaps inoperative to the radius of turn for a given condition plotted against indicated airspeed. On these figures the curves designated "stall limit, no flap" define the radius of turn as limited by stalling rather than by available thrust. Thus, at speeds below that at which the stall-limit curve intersects the main curve, the airplane cannot turn with smaller radii than those shown by the stall-limit curve unless the available lift is increased, that is, unless flaps or other high-lift devices are used. The portion of the main curve to the left of the stall-limit curve gives the radius of turn with flap deflected to the optimum positions; that is, the position which, at a given speed, will give the smallest radius of turn under the prescribed conditions.

The effect of the various types of flap on the radius of turn where the turn is limited only by stalling is shown in figure 17 for an indicated speed of 110 miles per hour. For this case it was assumed that the speed was held constant during the turns so that inequality between thrust and drag must be made up by varying altitude. Each curve corresponding to a given flap arrangement represents a varying maximum lift coefficient obtained by continuously varying the flap position.

<u>Use of turning-performance charts.</u>- The method of using the charts of figures 3 to 11 is shown by the following examples:

<u>Example A.</u>- Determine the radius R, the time t, and the normal acceleration n for a steady full-throttle 180° turn at an altitude of 25,000 feet and an indicated airspeed of 110 miles per hour for the normal condition of the airplane with a part-span NACA slotted flap deflected 20° (fig. 3).

The values of σR, $\sqrt{\sigma}t$, and n are read directly from the chart at the point on the γ curve representing the prescribed conditions. It is found that

$$\sigma R = 830 \text{ feet}$$

$$\sqrt{\sigma}t = 16 \text{ seconds}$$

$$n = 1.35g$$

Inasmuch as at 25,000 feet, $\sigma = 0.448$

$$R = \frac{830}{0.448} = 1850 \text{ feet}$$

$$t = \frac{16}{\sqrt{0.448}} = 24 \text{ seconds}$$

Example B.- Determine the radius, the time, the normal acceleration, and the change of altitude for the shortest 180° turn that can be made without stalling for the same airplane condition, altitude, and speed as for example A, on the assumption that the speed is held constant.

For this case the characteristics of the turn are defined by the point on the stall-boundary curve for $\delta f = 20^\circ$ corresponding to the indicated speed of 110 miles per hour. The values of σR, $\sqrt{\sigma}t$, and n are again read directly from the chart (fig. 3) and are shown to be

$$\sigma R = 405 \text{ feet}$$

$$\sqrt{\sigma}t = 7.9 \text{ seconds}$$

$$n = 2.25g$$

and, as in example A,

$$R = \frac{405}{0.448} = 905 \text{ feet}$$

$$t = \frac{7.9}{\sqrt{0.448}} = 11.8 \text{ seconds}$$

Because for this case $\Delta\gamma$ and γ are not equal, there will be a change of altitude (if the speed is held constant) given by

$$\Delta h = \frac{1.47\ V_{i\,l_s}(\gamma - \Delta\gamma)\ (\sqrt{\sigma}\,t)}{\sigma}$$

so that, from the information given in figure 3,

$$\Delta h = \frac{1.47 \times 110 \times 5.84\ (0.0098 - 0.0415) \times 7.9}{0.448} = -528\ \text{ft.}$$

Effect of flaps for steady level turns.- From the results of the present analysis it appears that flaps become effective for improving turning performance only at speeds below the speed at which turning without flaps is limited by stalling. For steady level turns with the normal condition of the airplane considered in the analysis, this speed is shown in figure 12 to be about 127 miles per hour, indicated airspeed, at an altitude of 11,000 feet and about 102 miles per hour at 25,000 feet; at a height of 35,000 feet steady level turns cannot be made with flaps down. Of the four part-span flap arrangements shown in this figure there appears to be little choice between the Fowler and slotted types or between the perforated and plain split flaps. The first two types are somewhat superior to the other two particularly at lower speeds and lower altitudes; for example, at 11,000 feet and 90 miles per hour the slotted and the Fowler flaps give about 15 percent smaller radius of turn than the split-type flaps.

The effect of increasing the flap span from 60 percent to full span is shown for the NACA slotted and the split-type flaps in figure 13. In both cases the reduction in radius of turn due to the increased flap span is of the order of 10 percent at an indicated airspeed of 90 miles per hour at 11,000 feet and about 5 percent at the same indicated speed at 25,000 feet. At 35,000 feet the flaps are again ineffective for level steady turns.

There appears to be a considerable advantage, where flaps are to be used for maneuvering, in providing for their rapid and, if possible, automatic adjustment to the best position for the particular conditions under which a turn is to be made; for example, with the part-span split flap the best level steady turn at an indicated airspeed of 90 miles per hour and an altitude of 11,000 feet is obtained with flap deflected about 30°. On the other hand, if a turn is attempted with this flap angle at a speed of 127 miles per hour, the smallest radius that could be maintained without loss of speed or altitude, as can be seen from figure 5, would be about twice as large as that which would be obtained with flaps up at the same speed. The use of flap angles other than the optimum would not be quite so serious for the lower-drag part-span flaps--that is, Fowler and slotted - although even for these the best flap angle for a speed of 90 miles per hour at 11,000 feet would give a radius about 20 percent greater than necessary at 127 miles per hour. (See figs. 3 and 4.)

Effects of supercharging and propeller diameter on level steady turns.- The calculations indicated that for the airplane with the original propeller the turning performance over the lower half of the speed range would not be materially improved at altitudes up to 25,000 feet by replacing the geared supercharger with the turbosupercharger (fig. 14). No large improvement was to be expected at 11,000 feet because the turbosupercharger was assumed to increase the engine power by only about 5 percent at this altitude, but at 25,000 and 35,000 feet the power was about 40 percent greater than that obtainable with the geared supercharger. At 35,000 feet the calculations indicated that the improvement in turning performance would be considerably greater because at this altitude a small increase in thrust gives a relatively large percentage of increase in excess thrust. From figure 1 it may be seen that the increase in thrust at 100 miles per hour at 35,000 feet is only about 5 percent which gives, according to figure 14, a reduction in turning radius of about 20 percent at this speed.

From the foregoing results it appears that to derive benefit at low speeds from the increased power output with the turbosupercharger it would be necessary to use a propeller designed to absorb the added power at lower and more efficient blade angles, that is, with greater diameter or greater solidity. The calculations were repeated therefore with the propeller diameter arbitrarily increased from 9.75 feet to 10.75 feet. With the turbosupercharger this change is shown to give a large improvement in turning performance particularly at the lower speeds and at high altitudes. It is shown that at 35,000 feet the part-span slotted flaps can now be used for steady level turns although over a rather limited speed range between about 75 and 95 miles per hour. The improved performance at the lower speeds with the larger propeller is obtained in spite of relatively large tip losses due to the high propeller tip speeds. At maximum speed at the lower altitudes some loss in performance is incurred by the high tip speeds but it appears relatively small and apparently vanishes at altitudes above 25,000 feet.

With the normal supercharger arrangement the increased propeller diameter again improves the turning performance at the lower speeds although to a much less extent than with the turbosupercharger. Furthermore, because with lower engine power the gain in efficiency to be realized by decreasing the blade angles is less, the effect of the tip losses is relatively greater so that there is a considerable detrimental effect on maximum speed particularly at the higher altitudes.

While the effect of increasing the solidity of the propeller (that is, the number of blades or the blade width) has not been considered in detail, it seems likely that this means of increasing propeller efficiencies at high altitudes would be considerably more effective than increasing the diameter because of smaller tip losses.

Effect of increased wing loading on steady level turns.- In figure 15 it is shown that a 20 percent reduction in wing area with aspect ratio held constant results in a marked deterioration in turning performance over the greater part of the speed range at all altitudes considered, primarily because of the increased span loading. At 11,000 feet the maximum speed is increased slightly but at altitudes above 25,000 feet the maximum speed is decreased by the increased wing loading. With the higher wing loading flaps, of course, become effective for reducing turning radius at somewhat higher speeds, for example; 139 miles per hour at 11,000 feet and 113 miles per hour at 25,000 feet.

Although the effect of reducing the wing area without changing the span has not been covered in detail in this analysis, it can be seen that in this case the turning performance would be adversely affected only at speeds below the stall limit. If, now the available lift coefficient were increased by the use of flaps to compensate for the increased wing loading - that is, to retain the same ratio of wing loading to maximum lift coefficient as for the original wing and hence, the same stalling speed - the turning performance at the lower speeds would be affected adversely only to a small extent. This effect is explained by the fact that at the lower end of the speed range the turning performance with a given available power will depend principally on the stalling speed and span loading so that, for the case considered, the effect of the increase in equivalent parasite area resulting from use of the flaps would be comparatively unimportant, as only a relatively small flap deflection (for example, about 15° with the part-span split flap) would be required to give the desired increase in maximum lift coefficient.

Turning with loss of speed or altitude.- Although the case of steady level full-throttle turns, previously discussed, provides a convenient basis for comparison of turning performance because the limiting factors, available power and stalling, are fairly well defined, it does not take account of all the conditions under which turns might be made. In combat a pilot, in order to evade the fire of his opponent, would probably turn as rapidly as possible within the limits imposed by his capacity to withstand normal acceleration or by stalling, not giving much consideration to the loss of altitude or speed which might result. As shown in figure 3 the greatest normal acceleration that can be developed in a level steady turn with the airplane under consideration is only about 2.5g at an altitude of 11,000 feet, about 1.7g at 25,000 feet, and about 1.1g at 35,000 feet. The speed in a combat starting at a high speed would probably decrease during the engagement until, with further reduction, stalling would unduly limit the maneuvers; rapid turning from there on would probably be accomplished by losing altitude if necessary.

It appears important to consider these cases, particularly in estimating the usefulness of flaps for improving the maneuverability of fighters. Inasmuch as turning under almost any conditions can be evaluated readily from the charts of figures 3 to 11, the case of turns with loss of speed or loss of altitude will be considered directly only insofar as is necessary to illustrate the effects on the applicability of flaps.

In figure 16 it is shown that, if a 10 percent loss of speed (assumed arbitrarily) can be tolerated in a turn through 180°, the turn can ~~can~~ be tightened to such an extent that the speed at which the stall is encountered without flaps is increased by 26 miles per hour at 11,000 feet and by about 20 miles per hour at 25,000 feet over the speeds at which turning will be limited by stalling if no loss of speed or altitude is permitted; the range of speeds over which flaps will provide an advantage in turning is therefore considerably increased at these altitudes. At 35,000 feet the 10-percent speed loss permits a large reduction in turning radius with flaps up but is not sufficient to warrant the use of flaps.

At the lower speeds in the range in which flaps would be likely to be used, the shortest possible turn would probably be made by permitting a loss of altitude, if necessary, rather than a loss of speed. Figure 17 shows the radii of turn and the rates of descent required for the shortest possible turns (limited by stalling) at an indicated airspeed of 110 miles per hour for the various part-span flap arrangements. Where turning is limited only by stalling it is obvious that flaps will always permit shorter turning regardless of altitude. It is shown that for reductions in the radius of turn up to about 15 percent of the radius without flaps at the given speed there is little advantage of one type of flap over another. In order to accomplish greater reductions in radius, however, the loss of altitude associated with the turning will be considerably greater for the high-drag types of flap (split and perforated) than for the low-drag types (NACA slotted and Fowler).

Here, again, the desirability of deflecting a flap, particularly one of the high-drag type, only as far as necessary to accomplish a desired result is shown by the following example: If a turn with a radius of 1500 feet is desired at an indicated airspeed of 110 miles and at a height of 35,000 feet, a deflection of slightly less than 15° would be required with the part-span split flap; the corresponding rate of descent would be about 3100 feet per minute. If the flaps were deflected instead to 30° for the same radius of turn, the rate of descent would be increased to about 4200 feet per minute. For the part-span slotted flap the increase in rate of descent that would be caused by using a flap angle of 30° instead of the best angle (about 15°) for the condition of the preceding example would be about 400 feet per minute.

CONCLUDING REMARKS

The results of the analysis indicate that, for the airplane considered, any of the flap arrangements investigated can be expected to give some improvement in low-speed turning performance as defined by steady level full-throttle turns at a given speed for altitudes up to about 25,000 feet.

If turning is not restricted to the condition of no loss of altitude or speed, then, of course, turns can be made at any altitude more quickly with flaps. Low-drag flaps such as the Fowler and the NACA slotted types are apparently somewhat superior to the split or perforated split types particularly if the flap position is not adjustable. At a given speed somewhat shorter turns should be possible with full-span flaps than with part-span flaps.

Turning performance over the lower half of the speed range for the airplane under consideration would probably not be materially improved at any altitude by increased supercharging of the engine unless the propeller were redesigned to absorb the added power more efficiently.

A reduction in wing area, if the aspect ratio is maintained constant, will result in impairment of turning performance over practically the entire speed range at all altitudes.

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TABLE I

CALCULATED LIFT-DRAG CHARACTERISTICS OF FIGHTER AIRPLANE WITH VARIOUS FLAP ARRANGEMENTS

Flap	$\frac{c_f}{c_w}$	$\frac{b_f}{b_w}$	δ_f (deg)	$C_{L_{max}}$	V_s (mph)	f (sq ft)	l_s (lb/sq ft)
Normal Wing Area							
None	---	---	---	1.42	84.6	6.2	5.59
NACA slotted	0.26	1.00	20	2.14	68.9	9.6	5.84
			30	2.33	66.1	12.2	6.07
			50	2.44	64.6	28.2	5.97
		.60	20	1.88	73.6	10.5	5.84
			30	2.01	71.1	14.0	5.90
			50	2.08	70.0	26.3	5.80
Fowler	.25	.60	0	1.76	76.0	8.3	5.99
			20	2.05	70.4	14.1	6.12
			40	2.22	67.7	26.9	6.33
Split	.30	1.00	15	1.84	74.3	17.7	5.37
			30	2.08	69.9	36.4	5.32
			45	2.27	66.9	60.3	4.78
		.60	15	1.70	77.4	14.6	5.37
			30	1.85	74.1	28.3	5.50
			45	1.97	71.9	44.8	4.93
Perforated split	.30	.60	15	1.61	79.5	12.3	5.37
			30	1.72	76.9	22.3	5.50
			45	1.80	75.2	34.4	4.93
Reduced wing area							
None		---	---	1.42	94.6	5.8	6.99
NACA slotted	.26	.60	20	1.88	82.3	9.2	7.30
			30	2.01	79.5	12.0	7.38
			50	2.08	78.3	21.8	7.25

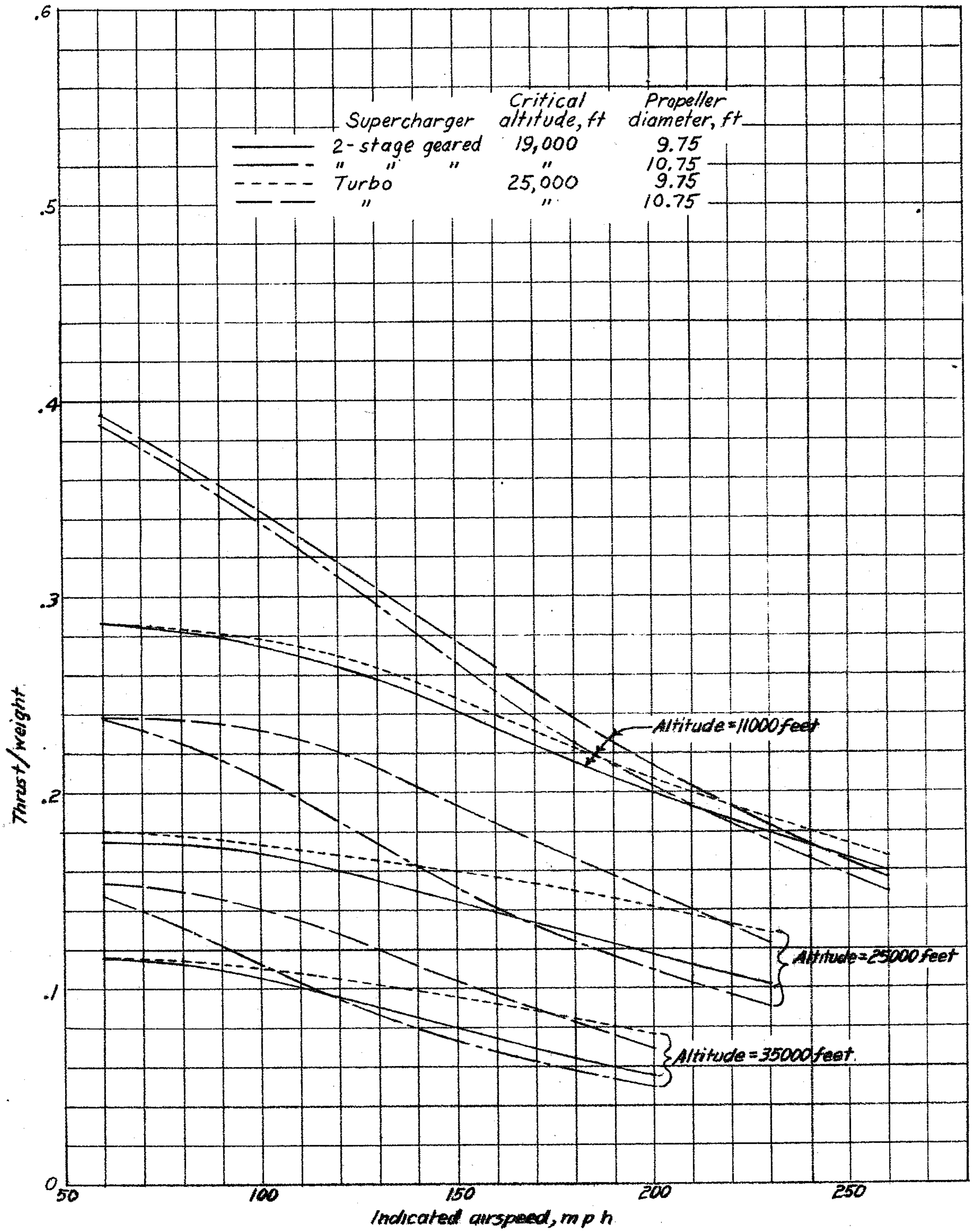
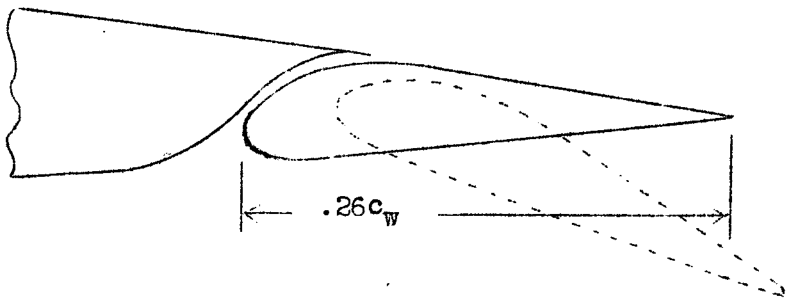
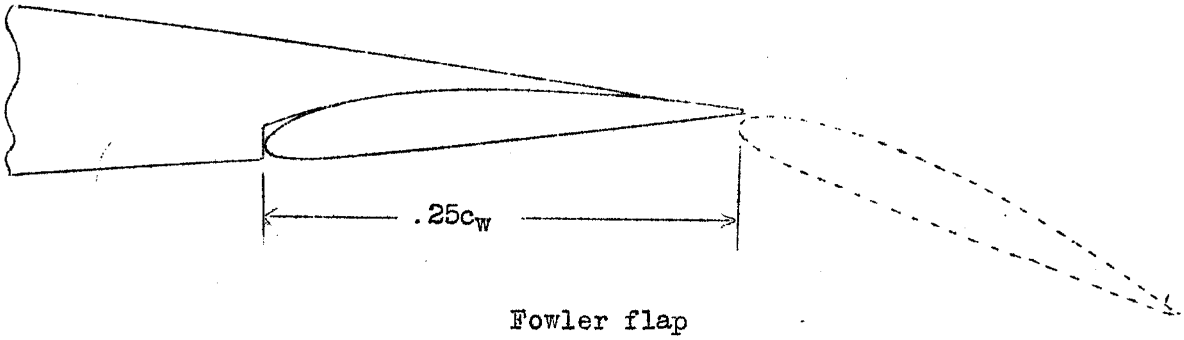


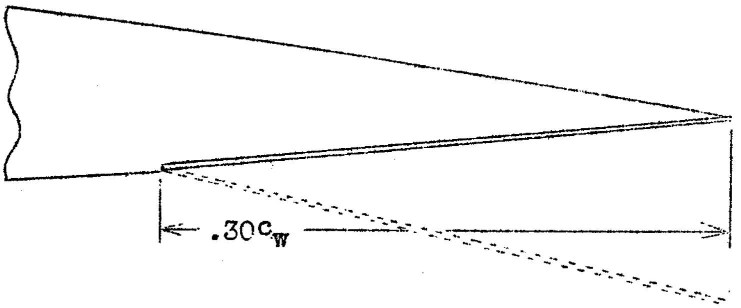
Figure 1.- Calculated thrust-loading curves. Fighter-type airplane; weight, 6800 pounds.



NACA slotted flap



Fowler flap



Split and perforated split flaps

Figure 2.- Section views of flaps.

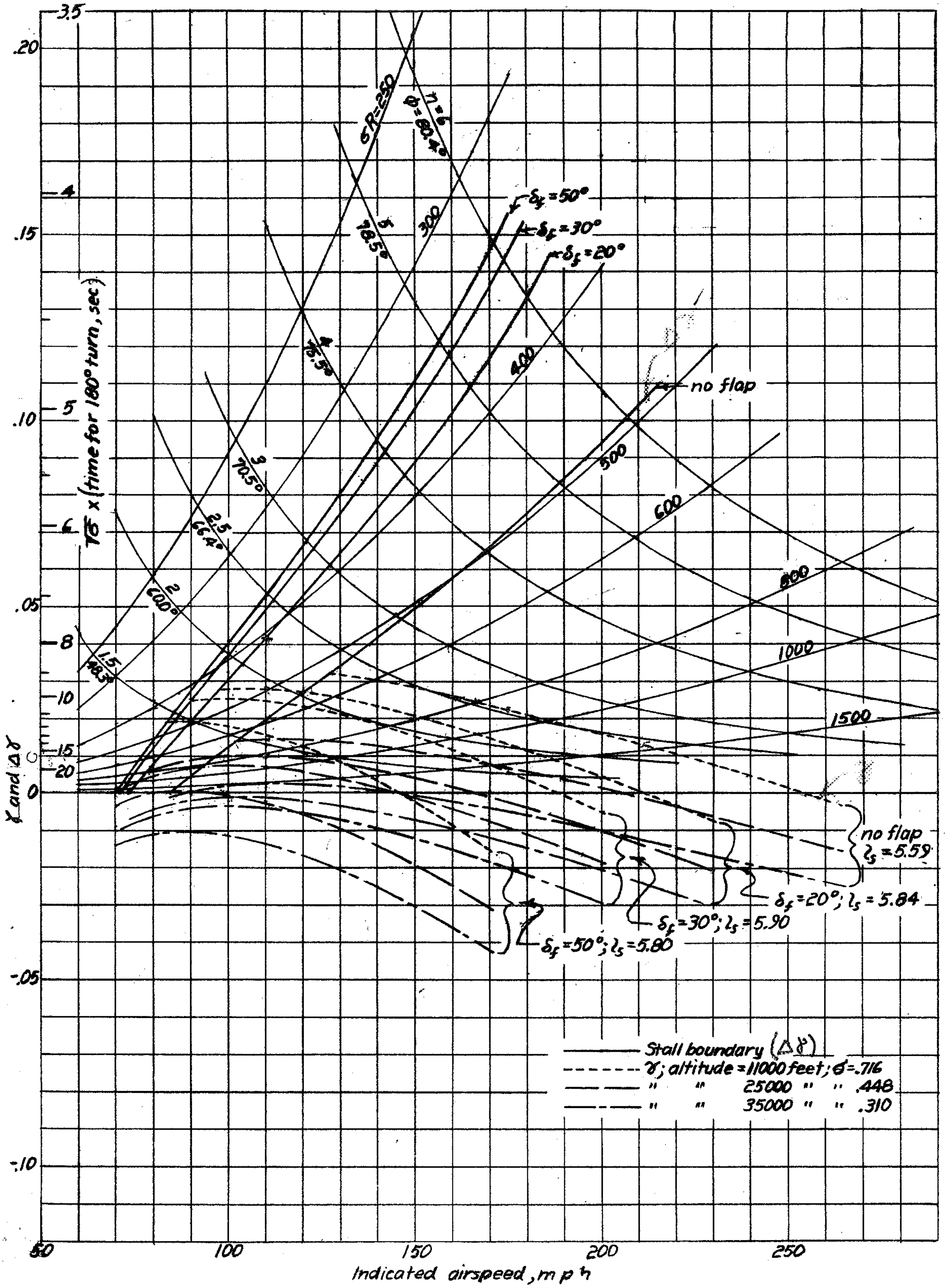


Figure 3. - Turning performance chart. Fighter-type airplane, normal condition, part span NACA slotted flaps.

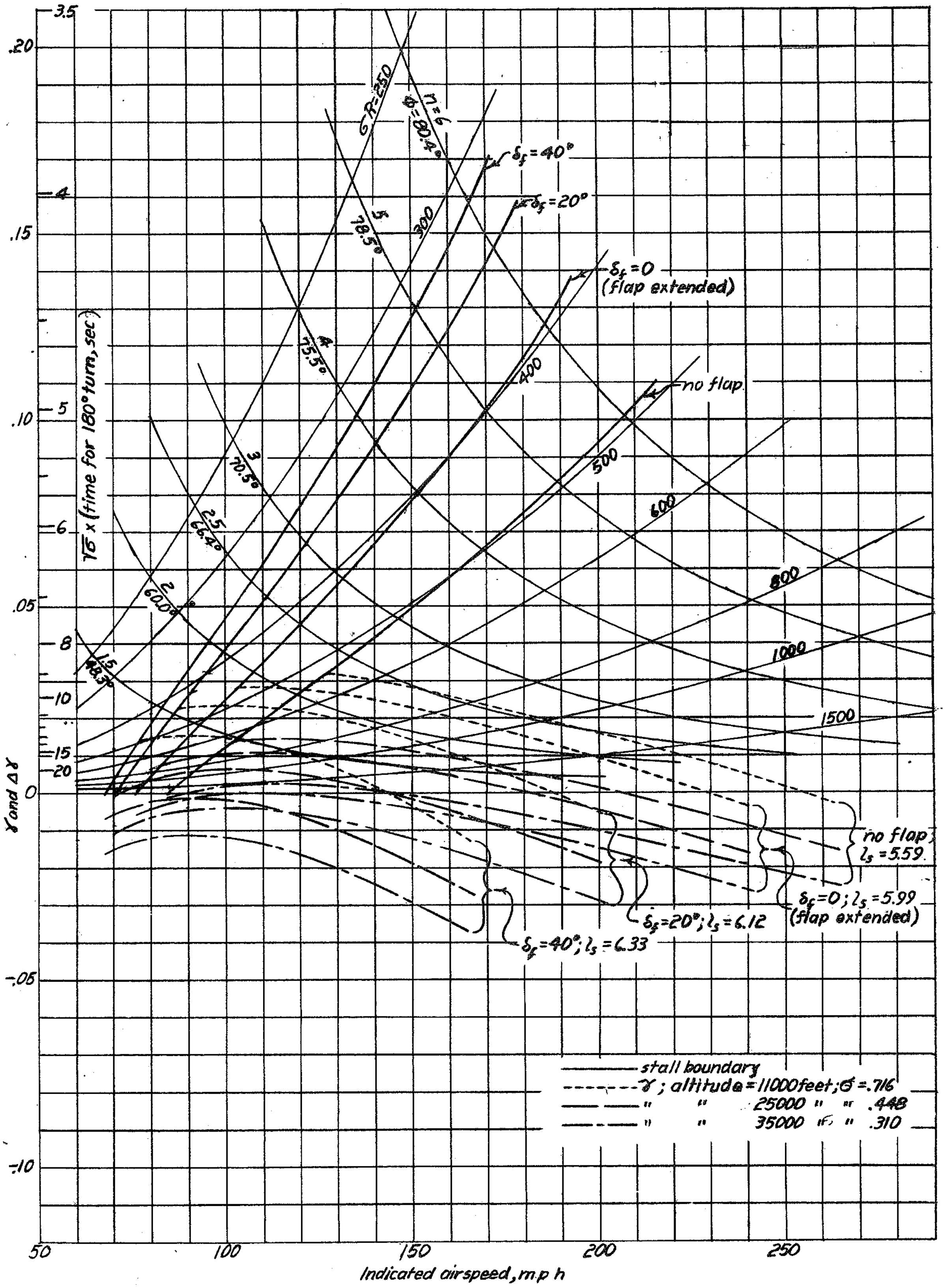


Figure 4: - Turning performance chart. Fighter-type airplane, normal condition part span Fowler flap.

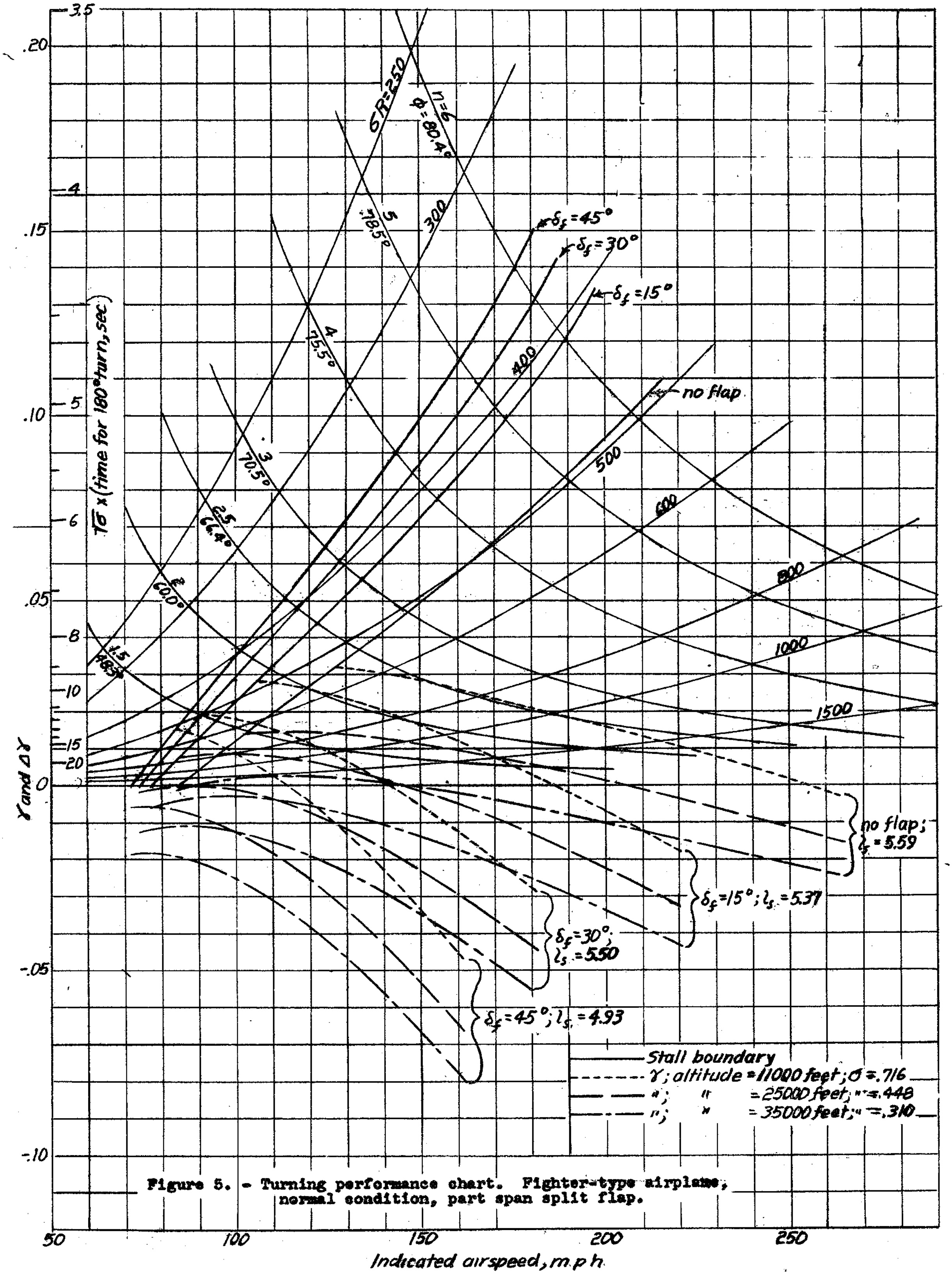


Figure 5. - Turning performance chart. Fighter-type airplane, normal condition, part span split flap.

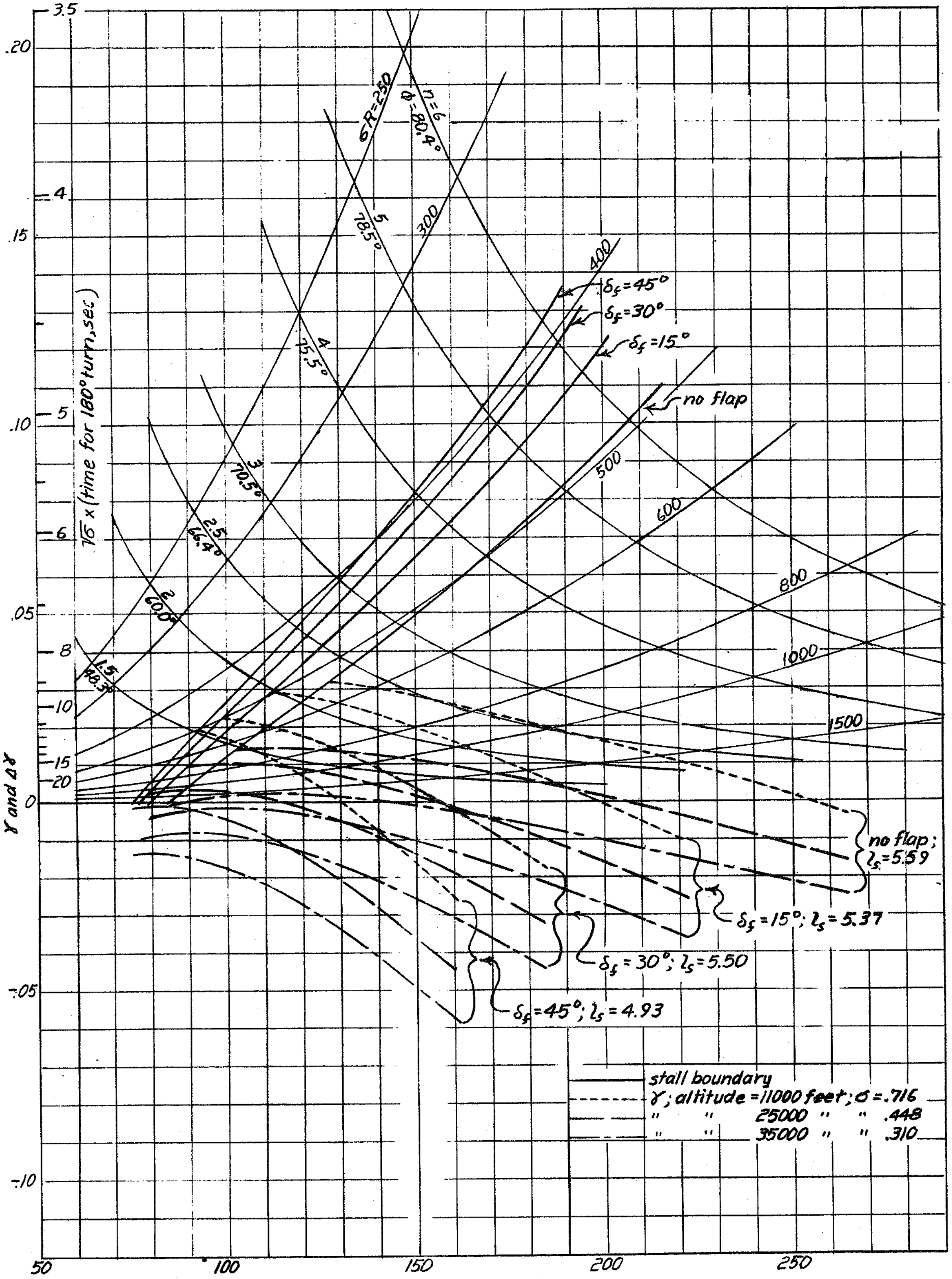


Figure 6. - Turning performance chart. Fighter-type airplane, normal condition, part span perforated split flaps.

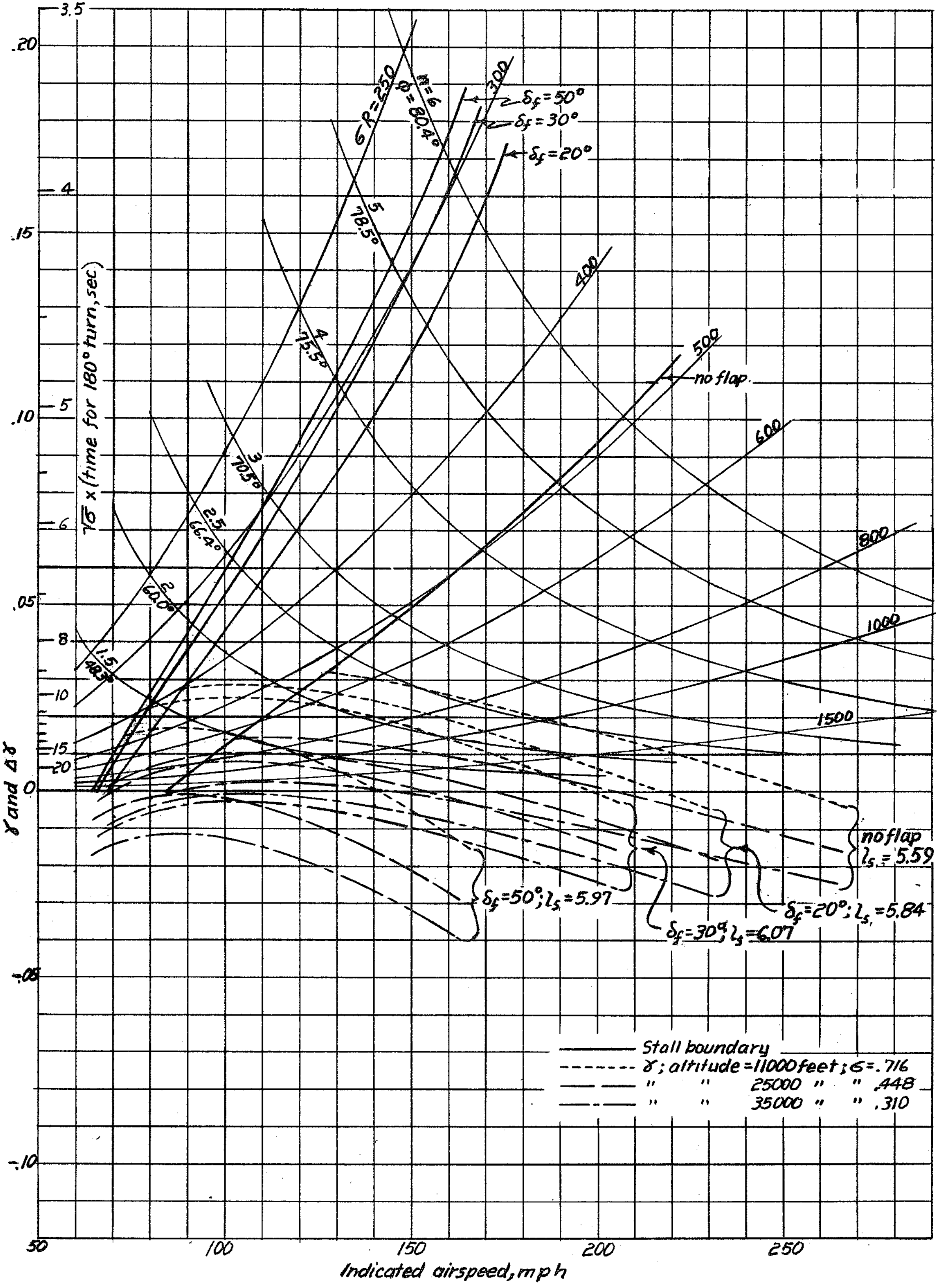


Figure 7. - Turning performance chart. Fighter-type airplane, normal condition, full span NACA slotted flaps.

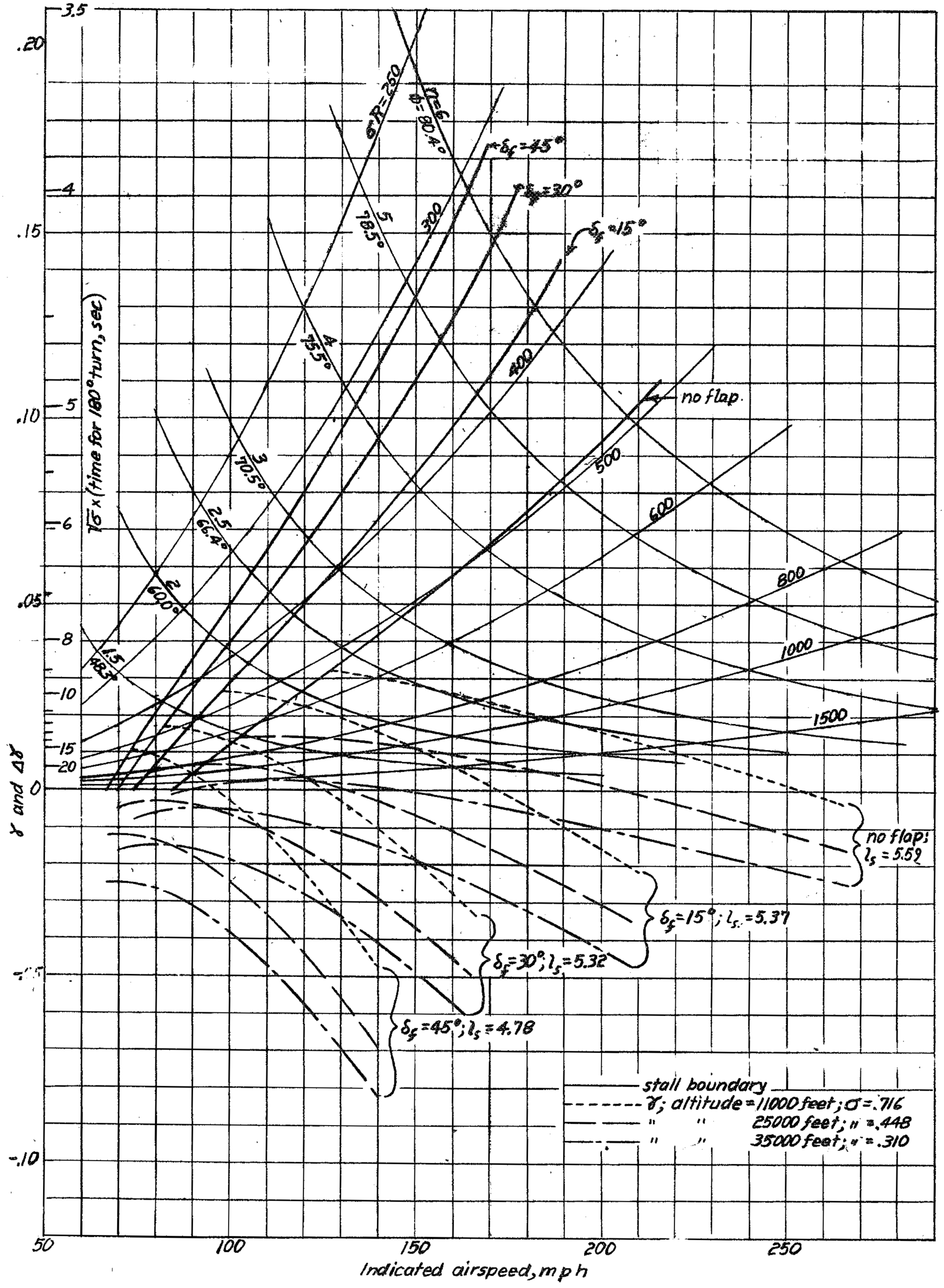


Figure 8. - Turning performance chart. Fighter-type airplane, normal condition, full-span split flaps.

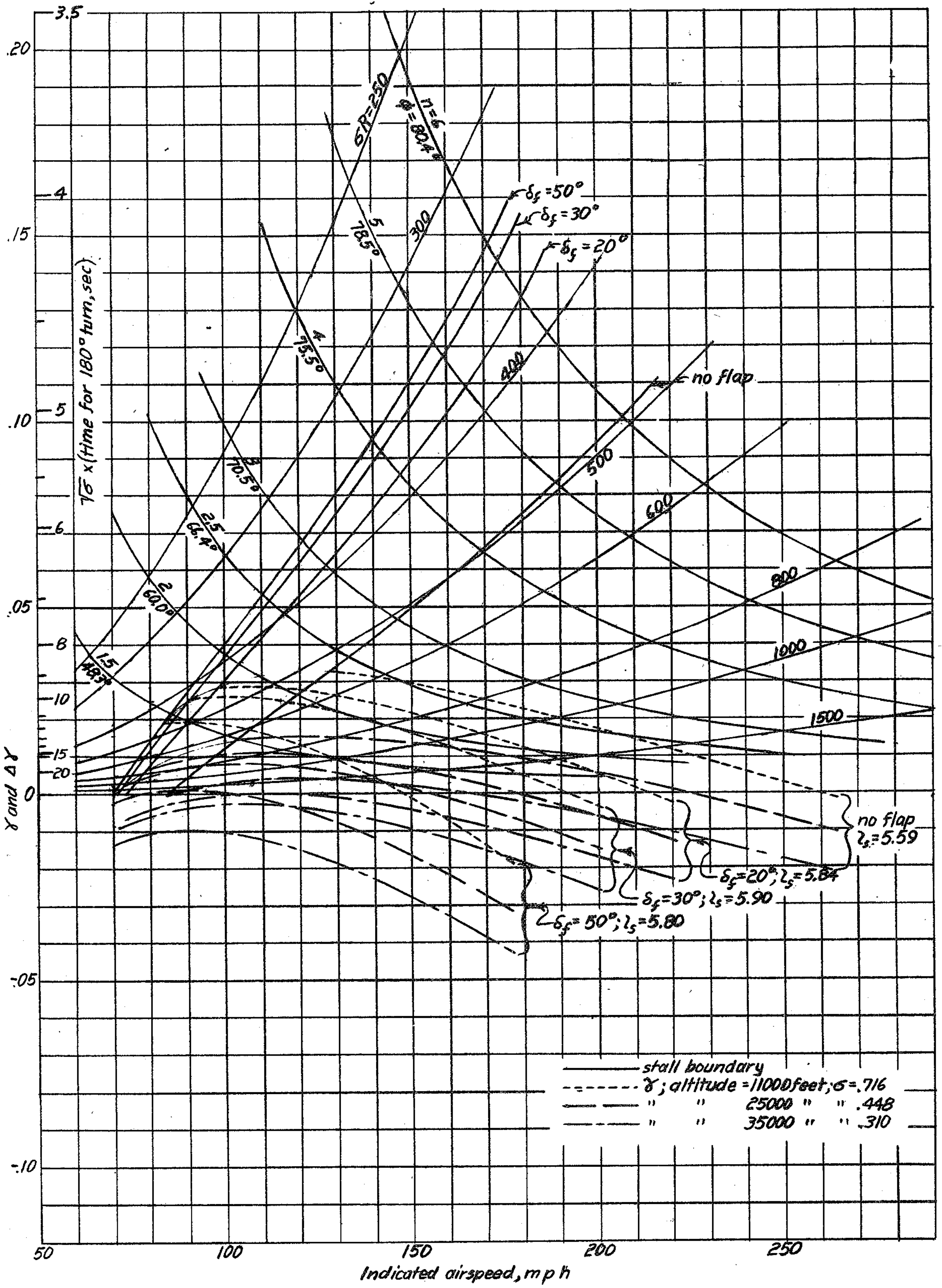


Figure 9. - Turning performance chart. Fighter-type airplane, turbosupercharger, propeller diameter 9.75 feet, part span NACA slotted flaps.

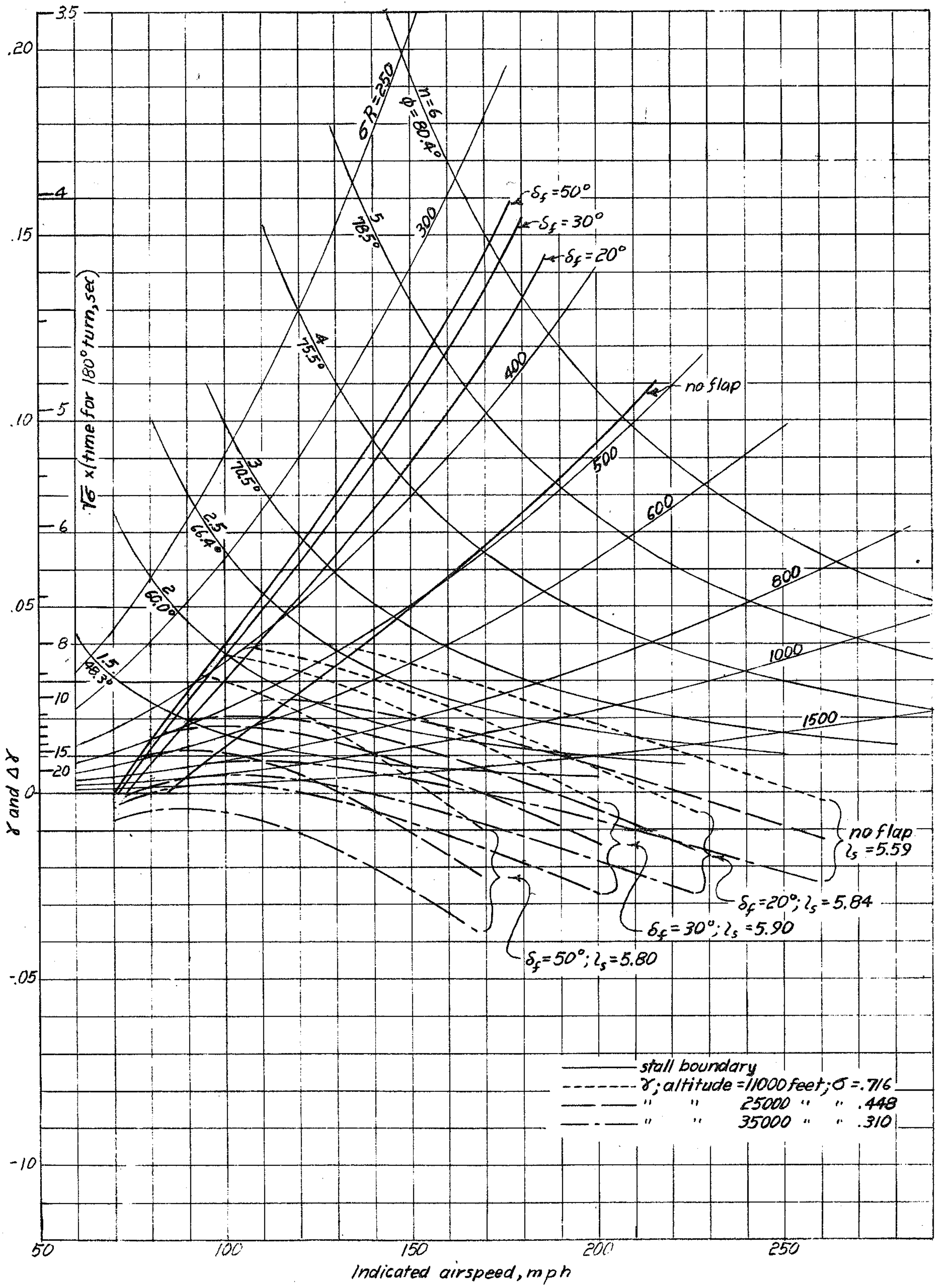


Figure 10. - Turning performance chart. Fighter-type airplane, turbosupercharger, propeller diameter 10.75 feet, part span NACA slotted flaps.

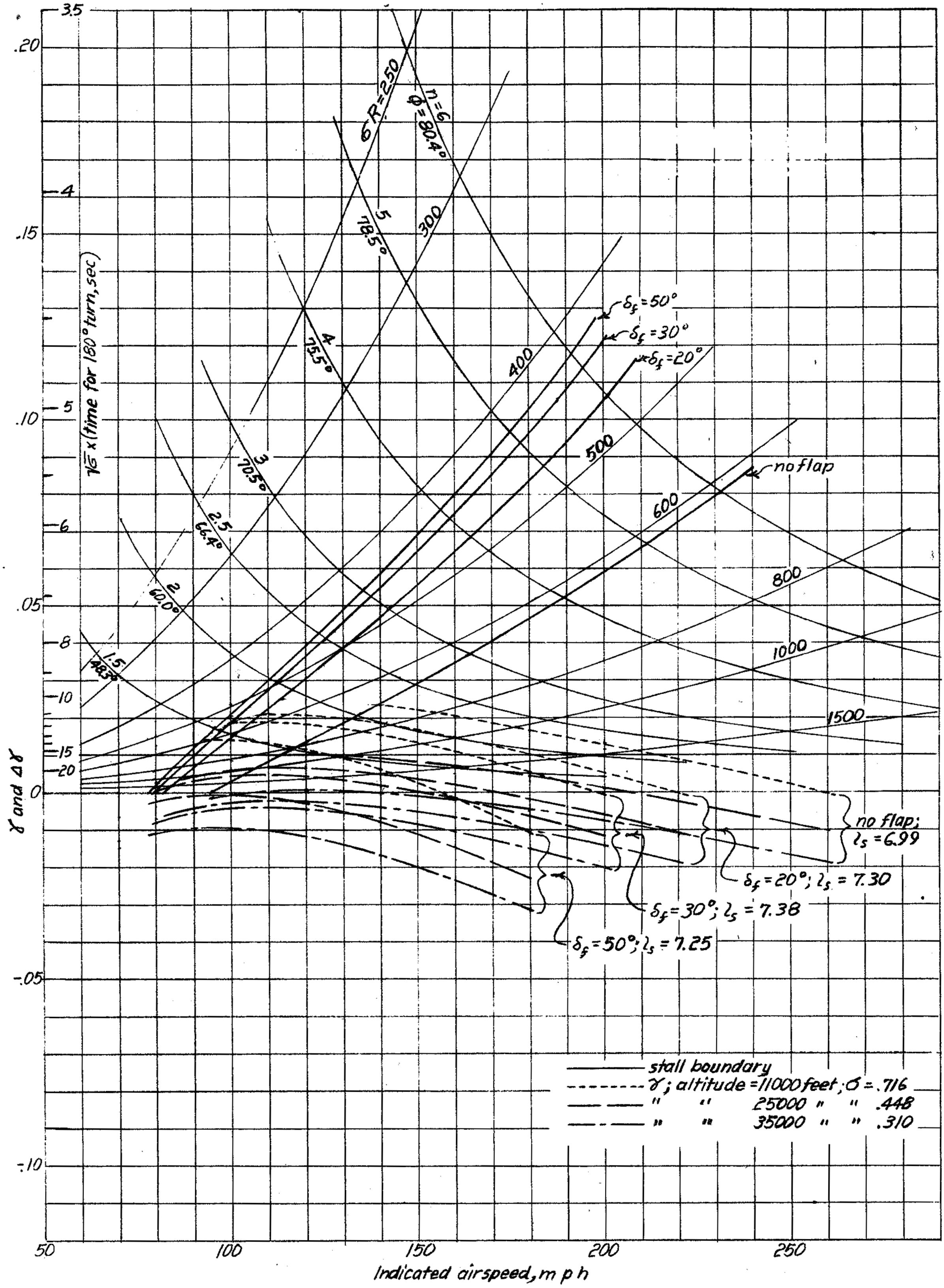


Figure 11. - Turning performance chart. Fighter-type airplane, wing area reduced to 208 square feet, part span NACA slotted flaps.

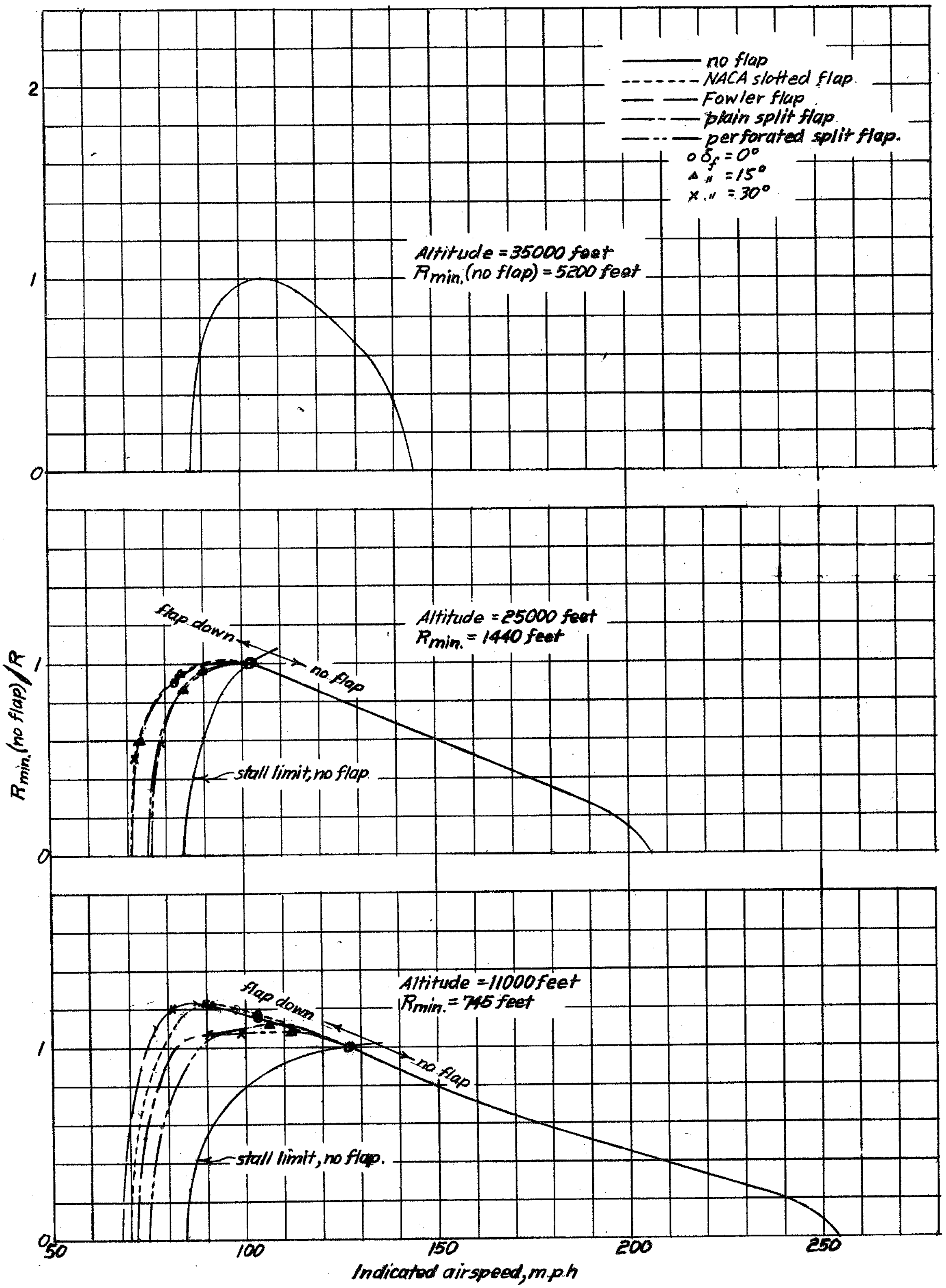


Figure 12.- Effect of part-span flaps of various types on turning radius. Fighter-type airplane, turns at constant speed and altitude. (R_{min} is minimum radius of turn without flaps.)

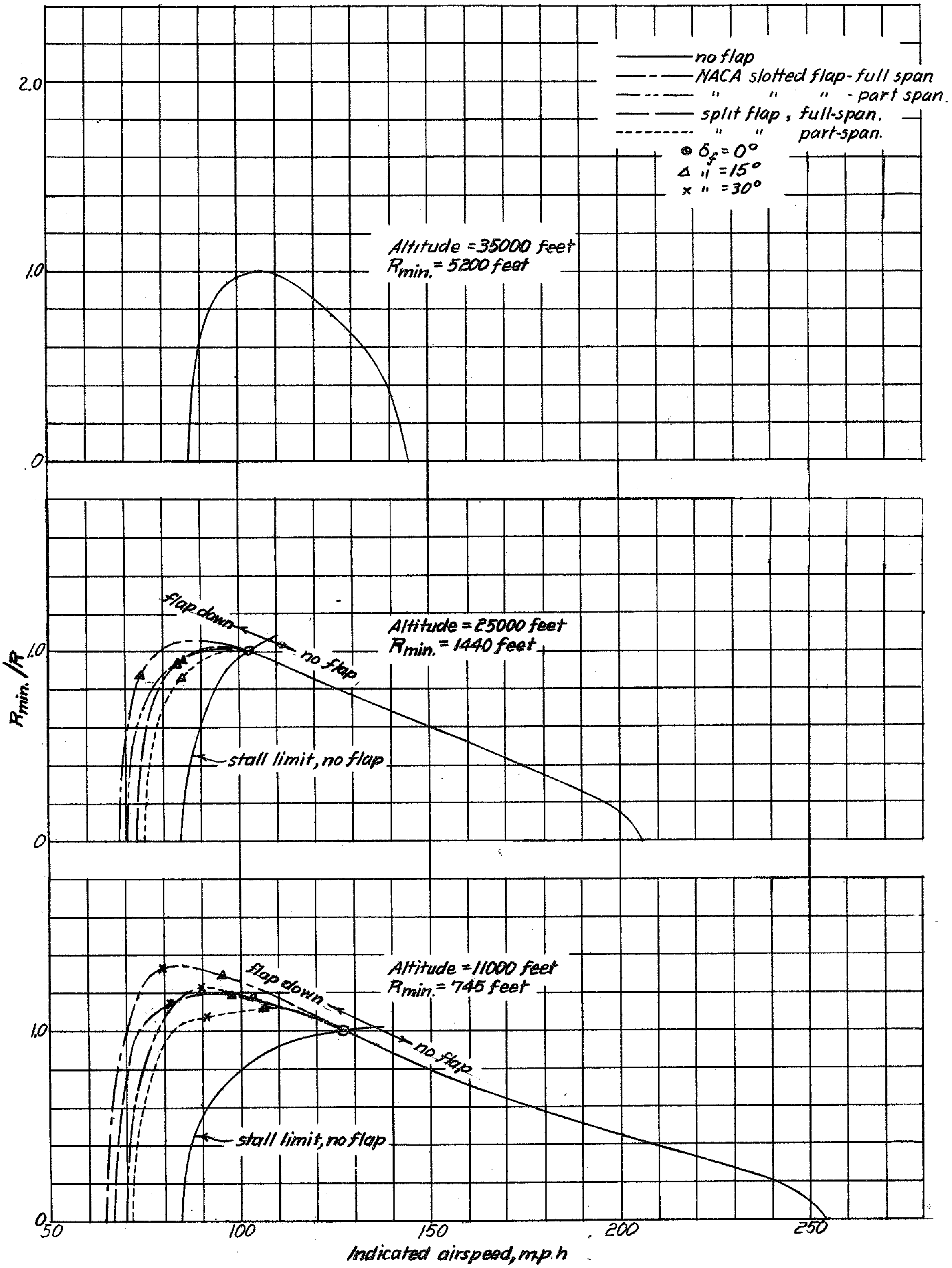


Figure 13.- Effect of flap-span on turning radius. Fighter-type airplane, turns at constant speed and altitude. (R_{min} is minimum radius of turn without flaps.)

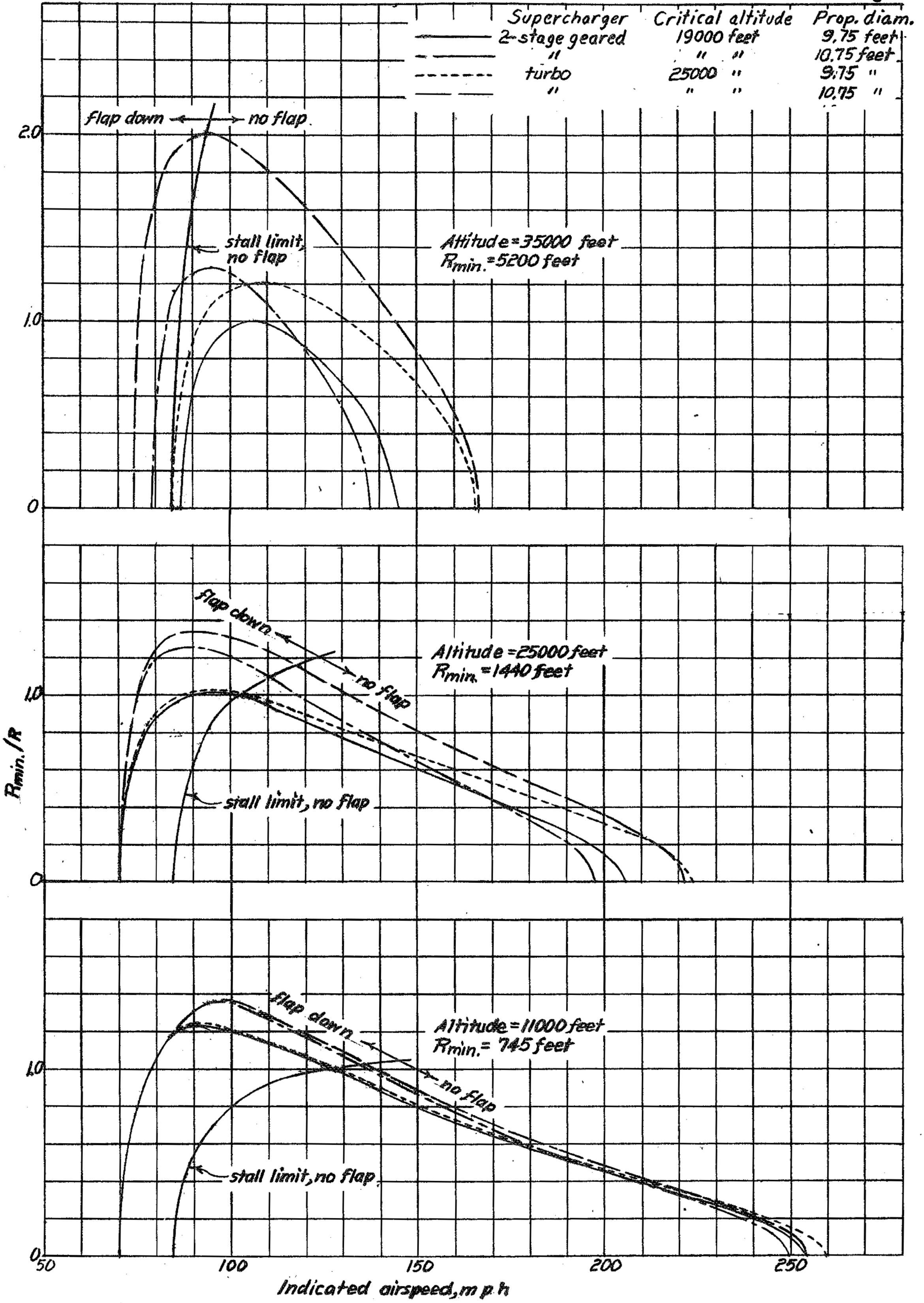


Figure 14.- Effect of supercharging and propeller diameter on turning radius. Fighter-type airplane, part-span slotted flaps, turns at constant speed and altitude. (R_{min} is minimum radius of turn with geared supercharger, 9.75-foot propeller, and no flaps.)

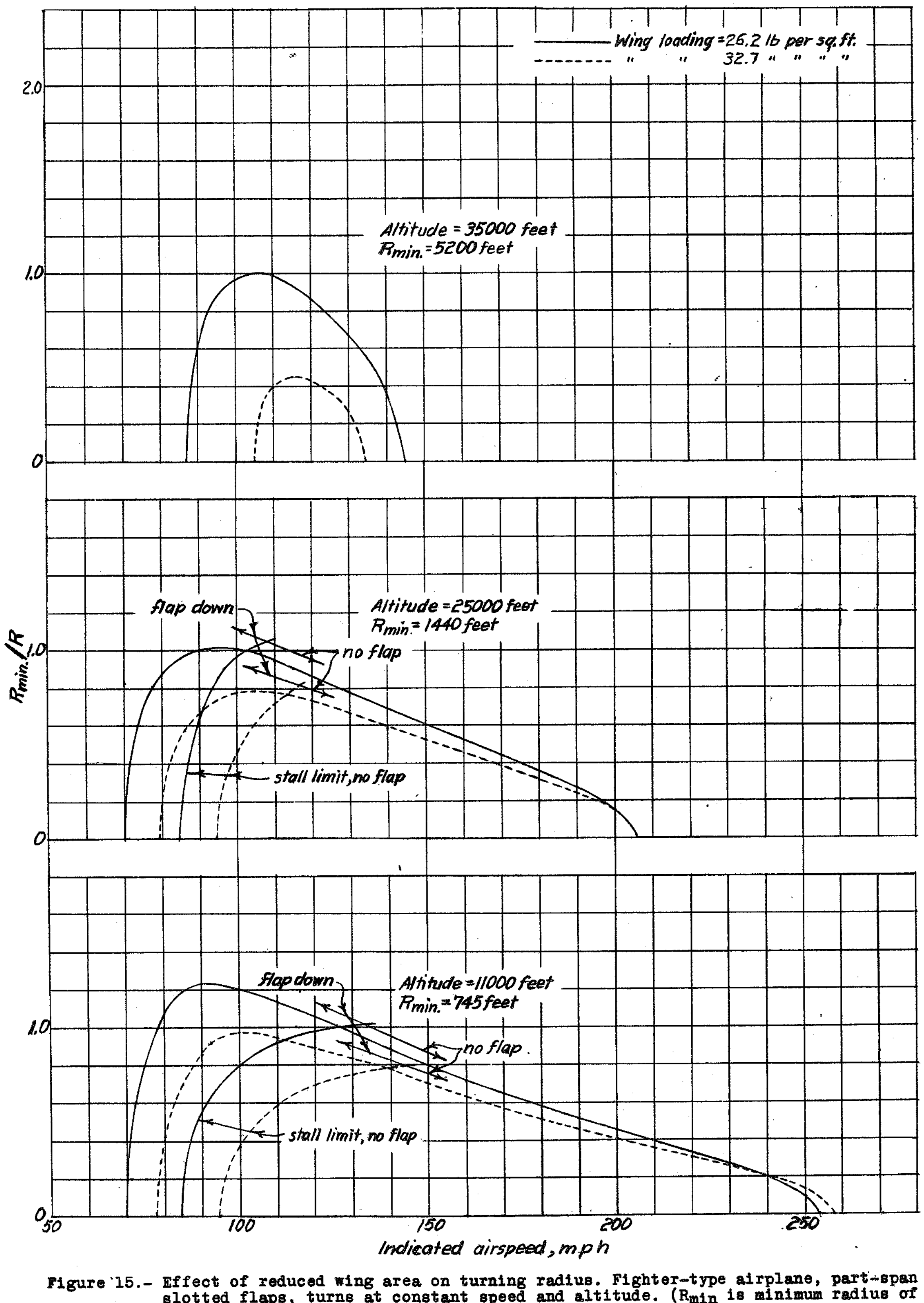


Figure 15.- Effect of reduced wing area on turning radius. Fighter-type airplane, part-span slotted flaps, turns at constant speed and altitude. (R_{min} is minimum radius of turn with wing loading 26.2 lb per sq ft, no flaps.)

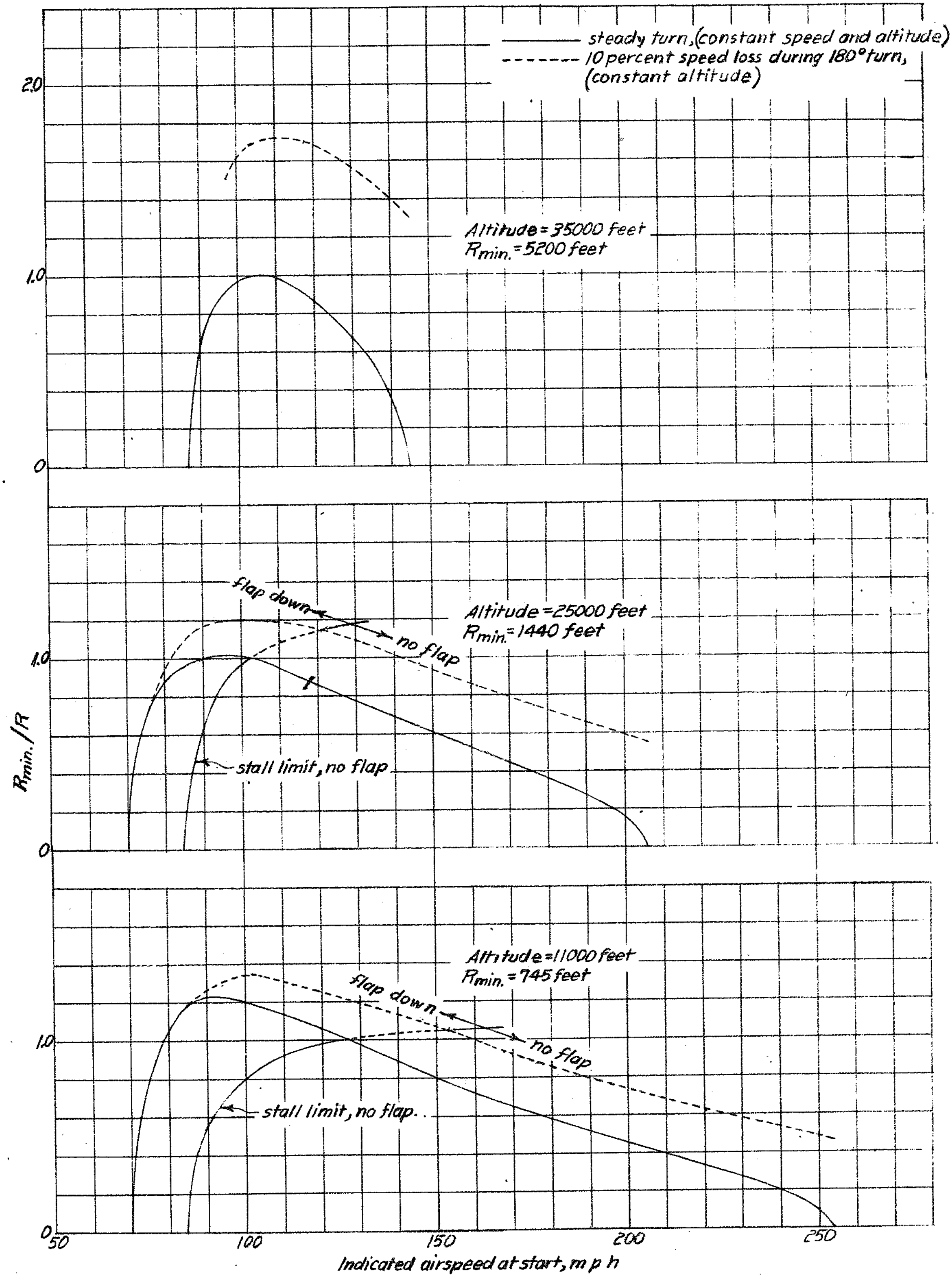


Figure 16.- Effect of deceleration on radius of turn. Fighter-type airplane, part-span slotted flaps. (R_{min} is minimum radius of turn at constant speed and altitude without flaps.)

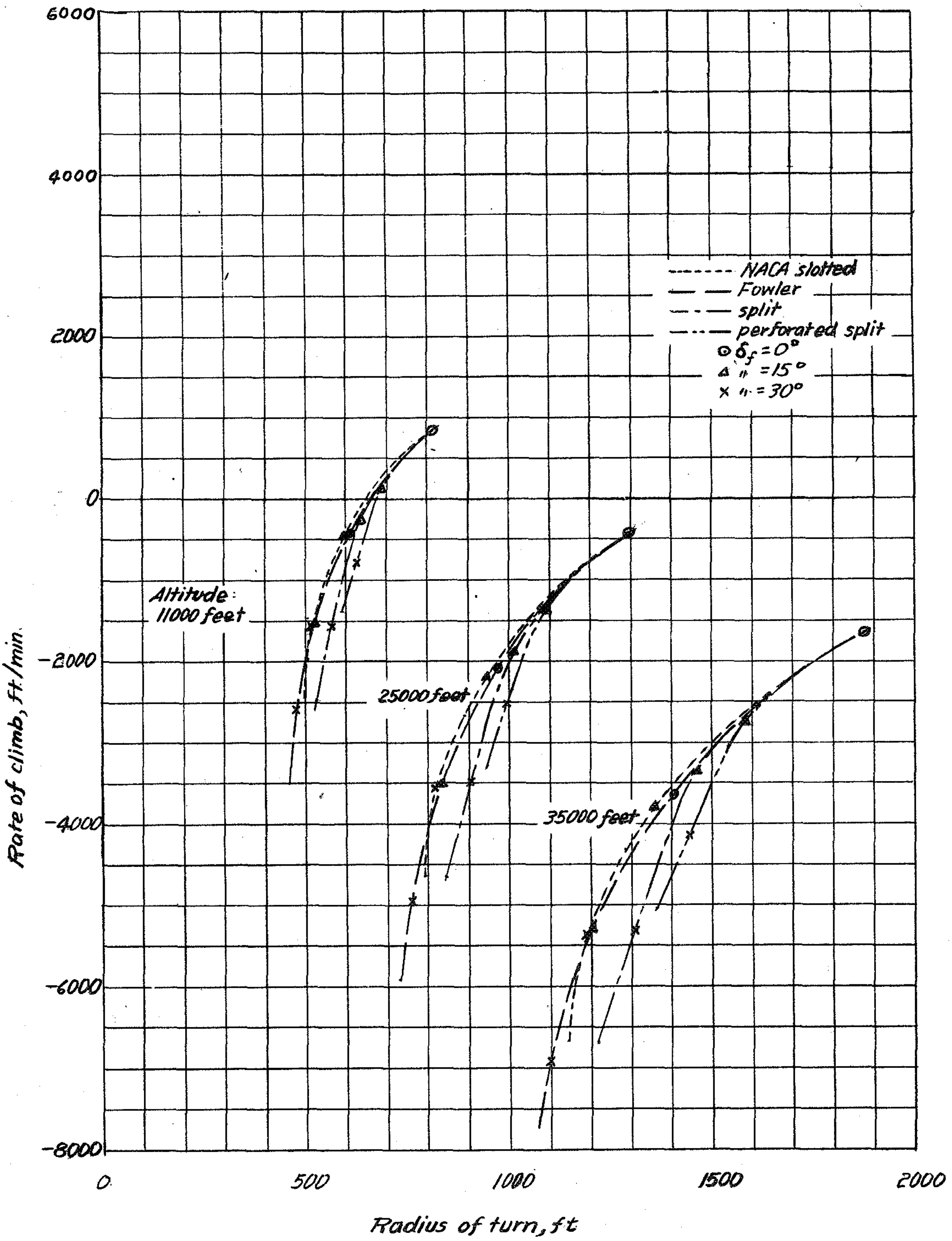


Figure 17. - Radius of turn at stall with part span flaps of various types. Fighter-type airplane, turns at a constant indicated airspeed of 110 miles per hour, varying flap position.