NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1329

TAIL-DESIGN REQUIREMENTS FOR SATISFACTORY SPIN RECOVERY FOR PERSONAL-OWNER-TYPE LIGHT AIRPLANES

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SUMMARY

The design requirements for airplane tail surfaces that would provide effective control for satisfactory recovery from fully developed spins of personal-owner-type light airplanes have been determined from an analysis of the characteristics of approximately 60 models previously tested in the Langley spin tunnels. Although these models did not represent actual personal-owner aircraft they had proportions of mass and dimensional characteristics representative of many airplanes in the personal-owner category.

A chart is presented that shows an empirical relationship between a tail-design parameter, relative density, and relative mass distribution of the airplane required for satisfactory recovery from fully developed spins.

For airplanes having values of relative density of 6 or less at the spin altitude, the tail-damping power factor required to insure satisfactory recovery by rudder reversal alone ranged from the small value 50×10^{-6} to the value 300×10^{-6}, approximately, as the inertia yawing-moment parameter varied from -120×10^{-4} to 120×10^{-4}. For airplanes having values of relative density between 6 and 10 at the spin altitude, the required tail-damping power factor was larger for corresponding values of mass distribution, ranging from 200×10^{-6} to 600×10^{-6}. If rudder reversal was followed by moving the elevator down, the tail-damping power factors required for the entire range of mass distribution considered were 50×10^{-6} and 200×10^{-6}, or less, for airplanes having values of relative density of 6 and 10, respectively.

INTRODUCTION

Spin investigations have been conducted in the Langley 15-foot and 20-foot free-spinning tunnels on approximately 150 different airplane designs to determine the spin and recovery characteristics of airplanes in fully developed spins. Approximately 60 of the designs tested had ratios of wing loading to wing span that are considered typical of airplanes in the personal-owner category (see fig. 1) and the results of tests of these models have been applied to the light-airplane spin problem. In order to provide effective control for satisfactory recovery from fully developed spins of personal-owner-type airplanes, a design requirement has been set up based on the same factors considered in determining the design requirement for military airplanes previously reported in reference 1. As before, for different values of airplane relative density, values of tail-damping power factor have been plotted against a nondimensional expression for the difference in moments of inertia about the airplane X and Y axes, and regions of satisfactory and unsatisfactory recoveries have been defined on the basis of results of the spin investigations of the models considered.

SYMBOLS

α	angle of attack, degrees
ρ	air density at a given altitude
ρ_0	air density at sea level (0.002378 slug per cu ft)
ρ_{5000}	air density at an altitude of 5000 feet (0.002049 slug per cu ft)

$$\frac{\rho_0}{\rho_{5000}} = 1.16$$

S	wing area, square feet
b	wing span, feet
W	weight, pounds
g	acceleration of gravity (32.17 ft per sec^2)

m	mass, slugs (W/g)
μ	airplane relative density ($m/\rho Sb$) $\left(\frac{13.1 \frac{W}{S}}{b} \text{ at sea level}\right)$
I_X, I_Y	moments of inertia about X and Y airplane axes, respectively, slug-feet^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
TDPF	tail-damping power factor (see fig. 2)
TDR	tail-damping ratio (see fig. 2)
URVC	unshielded rudder volume coefficient (see fig. 2)

METHODS

The analysis was made by plotting the tail-damping power factor as a function of the inertia yawing-moment parameter for each model considered. Lines were then drawn on the plots separating models possessing satisfactory characteristics from those possessing unsatisfactory characteristics as regards their ability to recover from fully developed, or established, spins by reversal of rudder alone and by reversal of both rudder and elevator. Plots were made for two relative-density ranges.

Tests

The recovery data used were obtained from routine tests made in the Langley 15-foot and 20-foot free-spinning tunnels. The methods for making these tests are described in reference 2. In recent years, however, the method of launching the model has been changed from launching from a spindle to launching by hand with spin rotation into the vertically rising air stream. Also, the clockwork mechanism has been replaced with a remote-controlled magnetically actuated mechanism. The data considered apply only to the model in the so-called clean condition, that is, with flaps up and landing gear retracted (except in case of fixed landing gear). Only conventional monoplanes produced during the years from 1935 to 1945 were considered in this investigation.

Results obtained by rudder reversal alone are presented because recovery from the spin can quite often be accomplished by this method. Spin-tunnel experience has indicated, however, that as the relative mass distribution along the wings is increased, the rudder loses effectiveness as a means of terminating the spin and the elevator gains effectiveness. Results obtained by reversal of both rudder and elevator are, therefore, also presented. Reversal of both rudder and elevator for recovery in the spin tunnel is made simultaneously because of limitations of the remote-control mechanism used for recovery tests. For recovery from airplane spins, however, the generally recommended procedure is that rudder reversal precede movement of the elevator down by approximately 1/2 turn in the spin. Movement of the elevator down prematurely may shield the rudder and thus decrease its effectiveness.

Factors Considered

As previously mentioned, in setting up the design requirement the factors considered were airplane relative density, tail-damping power factor, and inertia yawing-moment parameter.

Relative density is an indication of the interaction of the inertia and aerodynamic forces and moments acting during the spin and recovery. In order to determine the values of relative density μ typical of light airplanes, wing loadings W/S were plotted against wing spans b considered representative of light airplanes. Current trends indicated that wing spans varied from 29 to 40 feet and wing loadings varied from approximately 6 to 24 pounds per square foot. The corresponding values of relative density, for sea-level air density, varied from approximately 2 to 9 (fig. 1).

Tail-damping power factor TDPF is an empirically determined parameter and its value is an indication of the effectiveness of the vertical tail in terminating a spin. The method of computing it, as explained in reference 1, is illustrated in figure 2. For models having twin vertical tails at the ends of the horizontal tail, the outside tail (left vertical tail in a right spin) is considered extremely effective in terminating the spin and the entire fin and rudder area is considered unshielded. The inside vertical tail is considered in the normal manner in determining the effective fin and rudder area. Any existing fuselage area below the horizontal tail is also considered in the normal manner. If the vertical tails are not at the ends of the horizontal tail, the unshielded effective areas are determined by drawing the usual wake lines from the leading and trailing edges of the horizontal tail.

The inertia yawing-moment parameter $\frac{I_X - I_Y}{mb^2}$ plotted as the abscissa of figure 3 is an indication of how the mass is distributed in the airplane, that is, whether there is more mass distributed along the wings or more along the fuselage. Increasing values of the parameter indicate increased distribution of mass along the wings or decreased distribution along the fuselage. As indicated in reference 3, this parameter may be used as an aid in predicting the effect of controls during the spin or recovery.

Ranges of values of the relative density and the inertia yawing-moment parameter selected were considered to be representative of the personal-owner type airplanes currently being produced or contemplated.

Analysis

In the analysis of the data the models that exhibited satisfactory recovery characteristics were separated from those that exhibited unsatisfactory characteristics. The criterion for satisfactory recovery used for military airplanes in reference 1 was modified somewhat in consideration of light airplanes, partly because of insufficient existing data and partly because of the desirability of a more rigid criterion for safety of light airplanes. For this investigation, recovery characteristics of a given design were considered satisfactory if recovery by full rapid rudder reversal took place in $2\frac{1}{4}$ turns or less for all elevator settings when ailerons were neutral. At any elevator setting other than full down, recovery characteristics were still considered satisfactory even though movement of the elevator full down was required in conjunction with rudder reversal if recovery took place in $2\frac{1}{4}$ turns or less. Although only aileron-neutral results were considered in the current investigation, aileron deflection in the spin may greatly affect recovery characteristics. As indicated in reference 3, the aileron effect in the spin will probably depend upon the mass distribution of the airplane and unless the probable aileron effect is known, ailerons should be left at neutral during the spin and recovery.

The regions of satisfactory and unsatisfactory recoveries were separated by two lines, one for recoveries by rudder reversal alone and the other for recoveries by reversal of both rudder and elevator. The lines, in general, were drawn above the highest value of tail-damping power factor that gave unsatisfactory recovery or below the lowest value that gave satisfactory recovery, depending upon which procedure led to the more conservative plot.

The existing data showed that it was possible to separate the satisfactory designs from the unsatisfactory designs for all airplanes having sea-level relative densities less than 5. As the relative density increased, the line of separation between satisfactory and unsatisfactory designs was raised, and a line was drawn for airplanes having sea-level relative densities in the range from 5 to 9. It appears that most present-day one- and two-place light airplanes fall in the first category, and that the heavier light airplanes, which include designs up to four-place airplanes, will probably fall in the second category. Inasmuch as the recovery characteristics of the model were classified in terms of satisfactory and unsatisfactory recoveries at a spin altitude of 5000 feet, values of relative density were determined at this test altitude and are higher than the sea-level values by the ratio of the air density at sea level to that at 5000 feet (1.16). The values thus become 6 and 10 at the spin altitude.

RESULTS AND DISCUSSION

The results of the present study are plotted in figure 3 for the ranges of relative density considered. The values of relative density are given in terms of the air density at 5000 feet. Thus, curves are presented for values of relative density of 6 and 10. From the data plotted, minimum values of TDPF required to insure satisfactory recovery from fully developed spins may be obtained for airplanes of the personal-owner type. Airplanes having values of the plotted factors that fall above their corresponding curves should recover satisfactorily and those having values that fall below the curve may not recover satisfactorily.

Values of the coordinates required at a given value of relative density to give satisfactory recovery by rudder reversal alone are indicated by the solid lines. As relative distribution of mass is increased along the wings or decreased along the fuselage, the rudder loses effectiveness and larger values of tail-damping power factor are required for satisfactory recovery by rudder reversal alone. If the elevator is used in addition to the rudder, for the loading conditions for which the rudder has decreased effectiveness, a lower value of tail-damping power factor is required for satisfactory recovery. These results are indicated in figure 3 by broken lines.

For the lighter airplanes $(\mu < 6)$ it appears that only a small value of the tail-damping power factor (50×10^{-6}) was required to insure satisfactory recovery regardless of mass distribution if rudder reversal was followed by moving the stick forward. For recovery by rudder reversal alone, however, the tail-damping power factor required was as much as 300×10^{-6}, approximately, for loadings where the mass distribution was relatively heavy along the wings $\left(\frac{I_X - I_Y}{mb^2} = 120 \times 10^{-4}\right)$. For heavier airplanes (μ approaching 10), it became increasingly important to consider the provision of a sufficient value of tail-damping power factor to insure satisfactory recovery. For satisfactory recovery by rudder reversal alone, the tail-damping power factor required varied from 200×10^{-6} to 600×10^{-6} as the corresponding value of $\frac{I_X - I_Y}{mb^2}$ varied from -120×10^{-4} to 120×10^{-4}. For these cases, it was indicated that movement of the elevator down would usually be of appreciable assistance in terminating the spin and the tail-damping power factor required was 200×10^{-6}, or less, over the range of mass distribution considered. As a factor of safety, however, it is considered desirable that a sufficiently large value of tail-damping power factor be provided to terminate the spin without the assistance of the elevator.

CONCLUSIONS

From spin-tunnel tests of approximately 60 airplane models considered typical of personal-owner-type airplanes an analysis has been made to determine the tail design requirements for satisfactory recovery from fully developed spins. The analysis indicated that:

1. The minimum value of tail-damping power factor which would allow satisfactory recovery by reversal of rudder increased with an increase in the value of airplane relative density and with increased relative distribution of mass along the wings.

2. For airplanes having values of relative density of 6 or less at the spin altitude, the tail-damping power factor required to insure satisfactory recovery by rudder reversal alone ranged from the small value of 50×10^{-6} to a value of 300×10^{-6} as the inertia yawing-moment parameter varied from -120×10^{-4} to 120×10^{-4}. As the relative density at the spin altitude increased to 10, the tail-damping power factor required ranged from 200×10^{-6} to 600×10^{-6}.

3. The minimum value of tail-damping power factor required for satisfactory recovery characteristics when both rudder and elevator are reversed increased only with an increase in relative density, so that, when rudder reversal was followed by moving the elevator down, the tail-damping power factors required throughout the range of mass distribution were 50×10^{-6} and 200×10^{-6}, or less, for airplane relative densities of 6 and 10, respectively.

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National Advisory Committee for Aeronautics
Langley Field, Va., April 23, 1947

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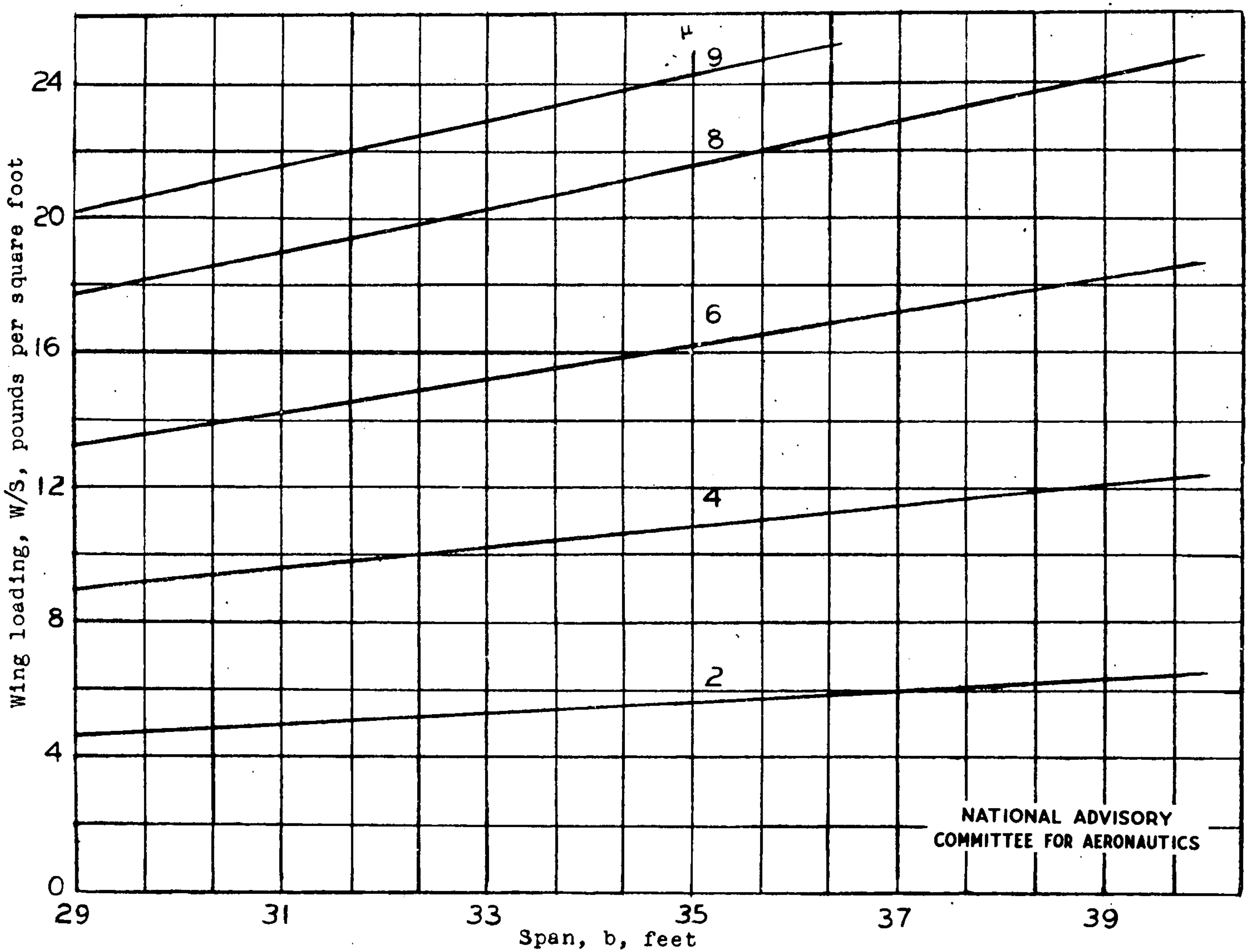
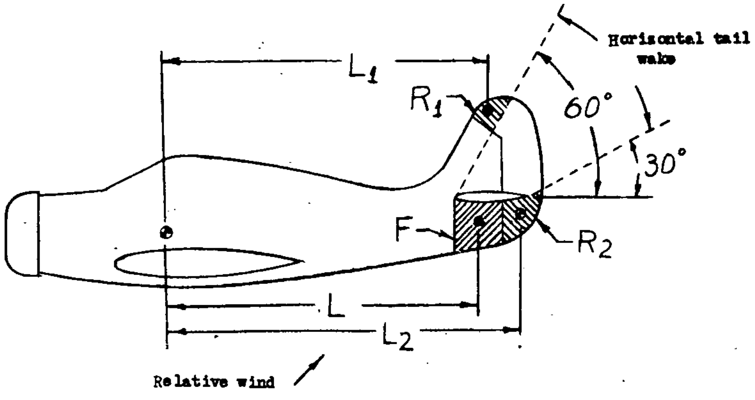
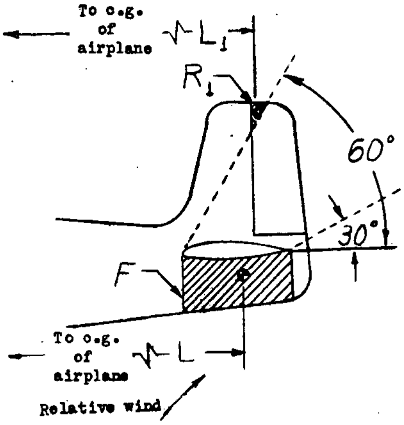


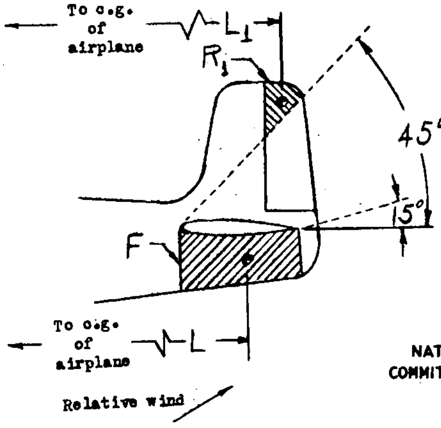
Figure 1.- Variation of relative-density factor with wing loading and span for personal-owner type airplanes (for sea-level air density).



(a) Full-length rudder; α assumed to be 45°.



(b) Partial-length rudder; α assumed to be 45°; TDR < 0.019.



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(c) Partial-length rudder; α assumed to be 30°; TDR > 0.019.

Figure 2.- Method of computing tail-damping power factor. Tail-damping power factor (TDPF) is the product of tail-damping ratio (TDR) and unshielded rudder volume coefficient (URVC).

$$\mathrm{TDPF} = \left[\frac{FL^2}{S(b/2)^2}\right]\left[\frac{R_1L_1 + R_2L_2}{S(b/2)}\right]$$

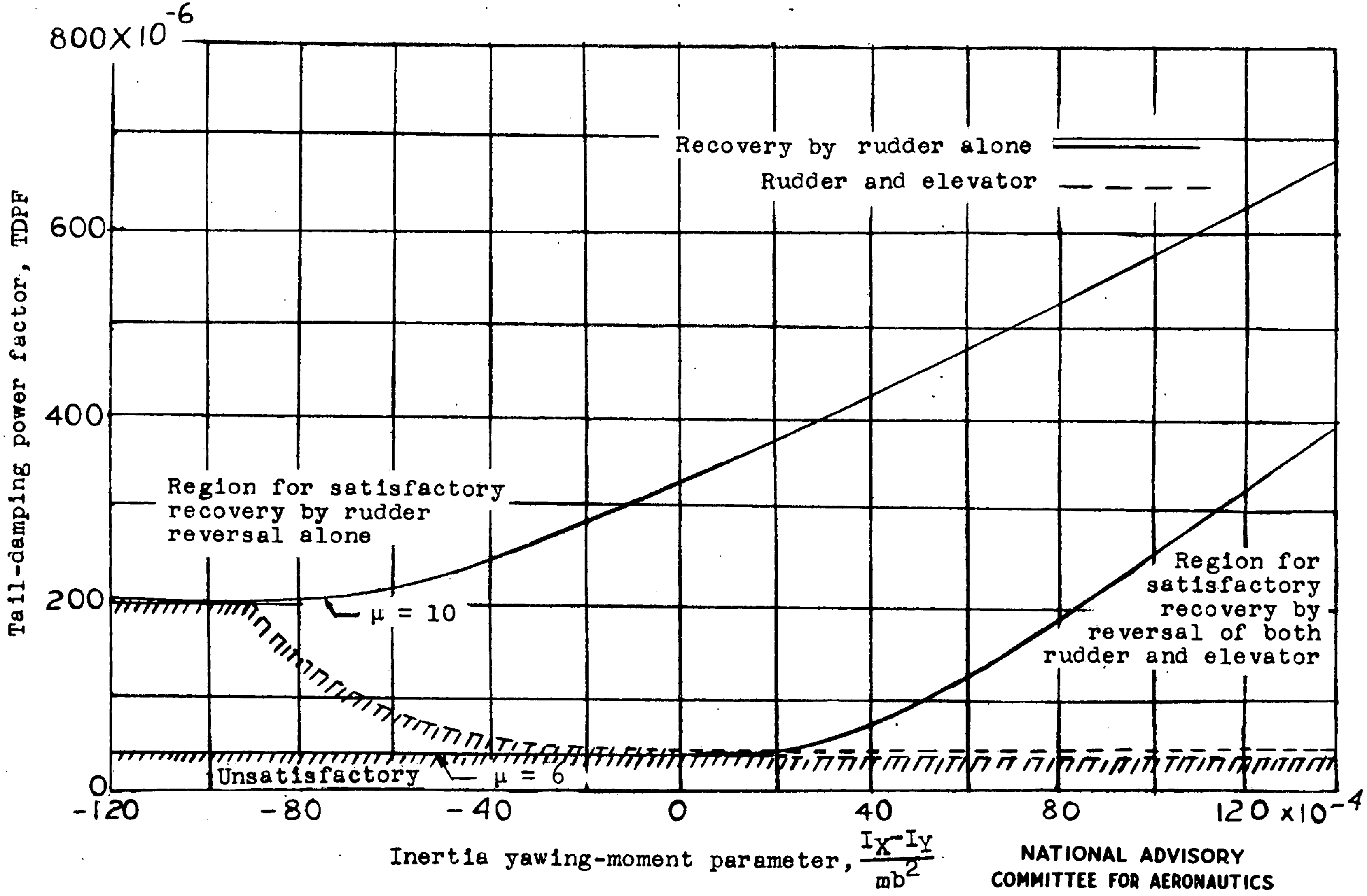

Figure 3.- Vertical-tail design requirements for personal-owner type airplanes.