

# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1045

TAIL-DESIGN REQUIREMENTS FOR SATISFACTORY

SPIN RECOVERY

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SUMMARY

The design requirements for airplane tail surfaces that would make recoveries from spins satisfactory have been investigated in an analysis of the characteristics of models of approximately 100 military airplanes. In the analysis, the relative distribution of mass along the wings and fuselage and the relative density of the airplane were considered as well as the design of the vertical surfaces.

A chart is presented that shows an empirical relationship between a tail-damping power factor and the relative density and mass distribution for satisfactory spin recovery. A formula for computing the tail-damping power factor is also given.

It was concluded that, if a designer provided a tail-damping power factor of  $600 \times 10^{-6}$  for airplanes for which the relative density at the spin altitude was not greater than 20, the probability that the airplane would have satisfactory recovery characteristics over a wide range of mass distribution by reversal of rudder and elevator would be very great. For larger values of relative density, larger values of tail-damping power factor would be required.

INTRODUCTION

The need for a reliable design requirement for airplane tail surfaces that will enable a designer to incorporate satisfactory recovery characteristics into a new airplane design has long been recognized. Recent British

and previous American research on this subject are presented in references 1 and 2, respectively. The previous American criterion indicated that a tail-damping power factor of  $150 \times 10^{-6}$  was a minimum requirement for obtaining satisfactory recovery characteristics by rudder reversal. Spin-tunnel data accumulated since the publication of reference 2 have shown that this requirement is inadequate inasmuch as the effectiveness of reversal of the rudder in producing recovery is dependent not only upon the tail-damping power factor but also upon the relative mass distribution and relative density of the airplane. Results obtained in reference 3 have indicated that, as the relative mass distribution along the wings of the airplane is increased, the effectiveness of the rudder as a spin-recovery device decreases, whereas that of the elevator increases. Also, it has been shown in reference 4 that, as the relative density of the airplane becomes greater, the effectiveness of the controls in producing recovery may be greatly decreased. In the present investigation the relative distribution of mass along the wings and fuselage of an airplane and the relative density of the airplane are considered as well as the design of the rudder (tail-damping power factor). The spin-recovery design requirements herein presented are empirical and are based on results of tests of models in the Langley 15-foot and 20-foot free-spinning tunnels of approximately 100 airplane designs. The models were tested with various tail modifications and mass changes and the results of these tests are also included.

#### SYMBOLS

a	angle of attack, degrees
$\rho$	air density at equivalent test altitude, slug per cubic foot
S	wing area, square feet
b	wing span, feet
m	mass, slugs
$I_x, I_y$	moments of inertia about X and Y airplane axes, respectively, slug-feet <sup>2</sup>

$\mu$	relative density of airplane at equivalent test altitude ( $m/\rho S b$ )
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
TDPF	tail-damping power factor
TDR	tail-damping ratio

### METHODS

The analysis was made by plotting the tail-damping power factor used in reference 2 as a function of inertia yawing-moment parameter for the various mass distributions for each model considered. Different symbols were employed to show whether the recovery characteristics were satisfactory or unsatisfactory when the recovery was attempted by rudder reversal alone or by simultaneous reversal of the rudder and elevator from steady spins for which the rudder was initially set full with the spin, the elevator was full up, and the ailerons were neutral (normal-spinning control configuration). Plots were made for three relative-density ranges. Lines were drawn on the plots that separate the regions for which recoveries were satisfactory from those for which recoveries were unsatisfactory.

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 5. The data herein include information for monoplane and biplane, landplane and seaplane, and single-engine and multiengine airplane designs. The data apply only to the models in the so-called clean condition, that is, with flaps up and landing gear retracted. Some of the older models had fixed landing gear. Results obtained by reversal of the rudder alone are plotted because the rudder has long been recognized as a primary control for recovery. Results obtained by reversal of the elevator in conjunction with the rudder are plotted because recent experience has indicated that as the rudder loses effectiveness as a primary control for recovery the elevator gains effectiveness.

The models were separated into those that exhibited satisfactory characteristics and those that exhibited unsatisfactory characteristics in recovering from established spins. The recovery characteristics were considered satisfactory if the model recovered in 2 turns or less from the spin when the model was in the normal-spinning control configuration and if small deviations from this control configuration did not cause recovery to exceed  $2\frac{1}{4}$  turns. This criterion for recovery has recently been in use for military airplanes at the Langley free-spinning tunnels. The results for the tests with simultaneous reversal of rudder and elevator may be somewhat conservative inasmuch as analysis of spin-tunnel results has indicated that recovery may be more rapid when full-rudder reversal precedes elevator reversal by  $1/2$  to 1 turn.

The tail-damping power factor was computed by the method indicated in figure 1. This method is the same as that used in reference 2 and was applied to all models except those having partial-length rudders and values of tail-damping ratio (also shown in fig. 1) in excess of 0.019. Analysis of spin-tunnel data has indicated that such models usually spin steeply and that recoveries are usually rapid even though the values of tail-damping power factor for these models, computed by assuming an angle of attack of  $45^\circ$  (reference 2), are relatively low. It was determined that, for models with partial-length rudder and tail-damping ratios (TDR) equal to or greater than 0.019, the angle of the relative wind in the tunnel was nearer  $30^\circ$  than  $45^\circ$ . The use of an angle of attack of  $30^\circ$  for the computation of the tail-damping power factor led to more consistent results for these cases than the use of an angle of attack of  $45^\circ$  and was used in this study. For models fitted with antispin fillets, the tail-damping power factor was computed by considering the fuselage area below the fillets as effective in damping rotation. The unshielded rudder area was, however, considered unchanged by the fillet.

The relative density and the inertia yawing-moment parameter were computed from the actual test conditions for particular model tests. The conditions generally bracketed the mass conditions specified by the manufacturer for the airplane represented. The inertia yawing-moment parameter is an index of the relative mass

distribution along the wings and fuselage of the airplane. The models were separated into the groups according to the value of the relative density and the data for each group were plotted separately. Models for which the values of  $\mu$  were 15 or less were placed in one group; models for which the values of  $\mu$  were greater than 15 and as much as 20 were placed in another group; and models for which the values of  $\mu$  were greater than 20 were placed in the third group.

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 simultaneous reversal of 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.

## RESULTS AND DISCUSSION

The results of the present study are plotted in figures 2 to 4 for various ranges of relative density. A composite curve is presented in figure 5. The spin-recovery design requirements are based on the primary factors of tail design and mass distribution. Other factors (such as wing design) undoubtedly influence recovery characteristics and may account in part for some mixture of the satisfactory and unsatisfactory points shown.

Data for models with relative densities  $\mu$  of 15 or less are plotted in figure 2. For values of inertia yawing-moment parameter of approximately  $-100 \times 10^{-4}$  or more in a negative direction, a value of tail-damping power factor of  $250 \times 10^{-6}$  is indicated as the minimum value that would offer a reasonable probability of satisfactory recovery by rudder reversal alone. For these values of the inertia yawing-moment parameter, the model is considered to be loaded chiefly along the fuselage (reference 3). The minimum tail-damping power factor for satisfactory recovery by rudder reversal alone is higher than that indicated in reference 2 and may be explained by previous lack of data between values of tail-damping power factor of  $150 \times 10^{-6}$  and  $250 \times 10^{-6}$ . For negative

values of inertia yawing-moment parameter smaller than  $-100 \times 10^{-4}$ , which are obtained when the mass is increased along the wings or decreased along the fuselage, the tail-damping power factor required for rudder reversal alone increased very rapidly. A value of tail-damping power factor of approximately  $1500 \times 10^{-6}$  was required for satisfactory recovery by full rudder reversal alone when the inertia yawing-moment parameter was zero. For negative values of the inertia yawing-moment parameter smaller than  $-70 \times 10^{-4}$  (approx.), the recoveries by simultaneous reversal of the rudder and elevator were usually more rapid than those by rudder reversal alone and, consequently, the tail-damping power factor required for simultaneous reversal of rudder and elevator was less than for rudder alone. For positive values of the inertia yawing-moment parameter, satisfactory recoveries were obtained by the simultaneous reversal of the rudder and elevator even when the value of the tail-damping power factor was less than  $100 \times 10^{-6}$ . This result is consistent with the results of reference 3, which indicated that for large spanwise loadings the elevator may become the primary control for recovery.

Data for models with relative densities greater than 15 and as much as 20 are presented in figure 3. The curve indicates that a value of tail-damping power factor of at least  $400 \times 10^{-6}$  is required to give satisfactory recovery by full, rapid rudder reversal for negative values of the inertia yawing-moment parameter of  $-100 \times 10^{-4}$  or greater. For smaller negative values, the required tail-damping power factor increases sharply. The curve generally falls above that previously obtained for the lower range of relative density. For satisfactory recoveries by reversal of rudder followed by elevator reversal for any given design over a wide range of mass distribution, a tail-damping power factor of at least  $600 \times 10^{-6}$  is apparently necessary.

In some instances, as shown in figures 2 and 3, the simultaneous reversal of the rudder and elevator led to unsatisfactory recovery characteristics although the reversal of the rudder alone led to satisfactory recoveries. This result may be attributed to the shielding of the rudder and the subsequent loss of effectiveness due to the downward movement of the elevator before the rudder was completely reversed. These points were disregarded in plotting the curves inasmuch as the recommended

procedure for the use of the controls (full rudder reversal followed approx. 1/2 turn later by elevator reversal) would probably have given satisfactory recovery.

Data for designs with relative densities greater than 20 (fig. 4) were rather meager but, in general, indicate that the required values of tail-damping power factor were further increased with increased relative density up to the maximum value available (35).

A composite of the curves in figures 2 to 4 is given for convenience in figure 5. When these curves are used, particular attention should be given to the range of inertia yawing-moment parameter expected for the airplane. In the region of mass distribution varying from values

of  $\frac{I_x - I_y}{mb^2}$  from  $-100 \times 10^{-4}$  to  $20 \times 10^{-4}$ , higher tail-

damping power factors are required than are necessary on either side of this region. If, in designing the airplane, consideration can be given to the mass distribution and this "critical" region can be avoided, a value of tail-damping power factor considerably lower than  $600 \times 10^{-6}$  indicated for relative densities of 20 or less may be acceptable.

#### CONCLUDING REMARKS

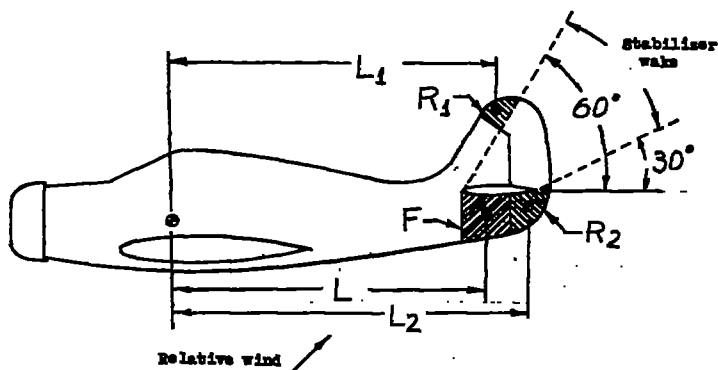
From spin-tunnel tests of approximately 100 military-airplane models, an analysis was made to determine a reliable design requirement for airplane tail surfaces. The data presented indicated that the minimum value of tail-damping power factor which would offer a reasonable probability of satisfactory recovery characteristics by reversal of both rudder and elevator for a wide range of mass distribution would be  $600 \times 10^{-6}$  if the relative density at the spin altitude were not more than 20. For higher values of relative density, larger values of tail-damping power factor would be required.

Langley Memorial Aeronautical Laboratory  
National Advisory Committee for Aeronautics  
Langley Field, Va., January 24, 1946

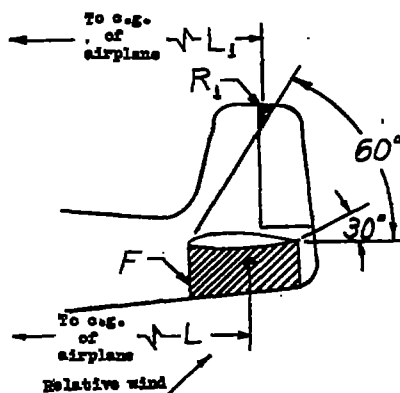


## REFERENCES

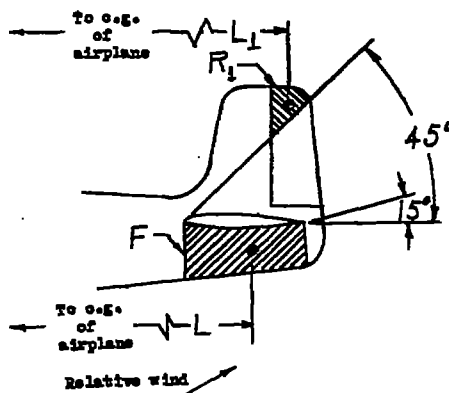
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2. Seidman, Oscar, and Donlan, Charles J.: An Approximate Spin Design Criterion for Monoplanes. NACA TN No. 711, 1939.
3. Neihouse, A. I.: A Mass-Distribution Criterion for Predicting the Effect of Control Manipulation on the Recovery from a Spin. NACA ARR, Aug. 1942.
4. Seidman, Oscar, and Neihouse, A. I.: Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. V - Effect of Airplane Relative Density. NACA Rep. No. 691, 1940.
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(a) Full-length rudder;  $\alpha$  assumed to be  $48^\circ$ .



(b) Partial-length rudder;  $\alpha$  assumed to be  $48^\circ$ ;  $TDR < 0.019$ .



(c) Partial-length rudder;  $\alpha$  assumed to be  $30^\circ$ ;  $TDR > 0.019$ .

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Figure 1.- Method of computing tail-damping power factor. Tail-damping power factor is the product of tail-damping ratio and unshielded rudder volume coefficient.

$$TDFP = \frac{FL^2}{s(b/2)^2} \times \frac{R_1L_1 + R_2L_2}{s(b/2)}$$

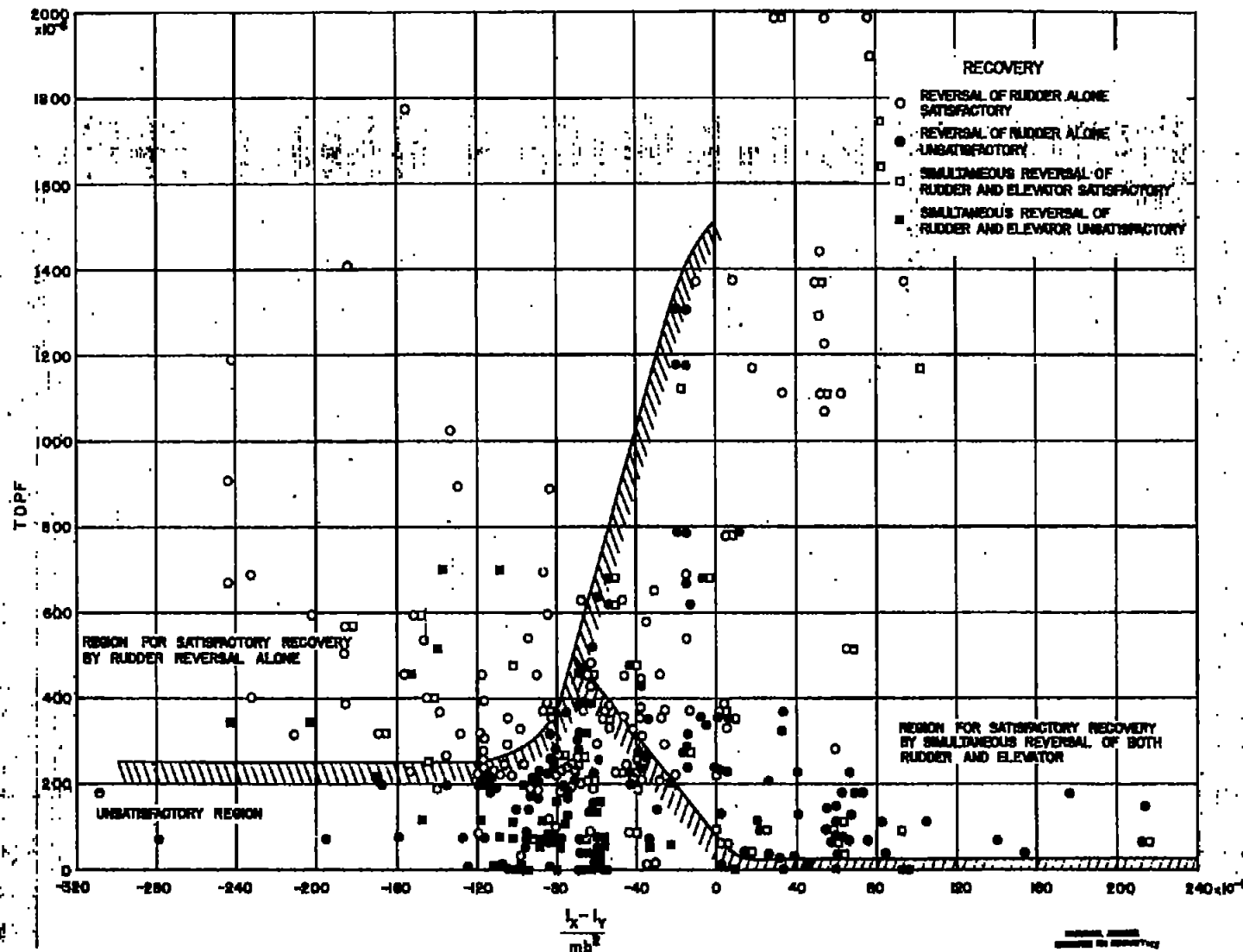


FIGURE 2- SPIN-RECOVERY DESIGN REQUIREMENTS FOR AIRPLANES WITH RELATIVE DENSITIES OF 15 OR LESS.

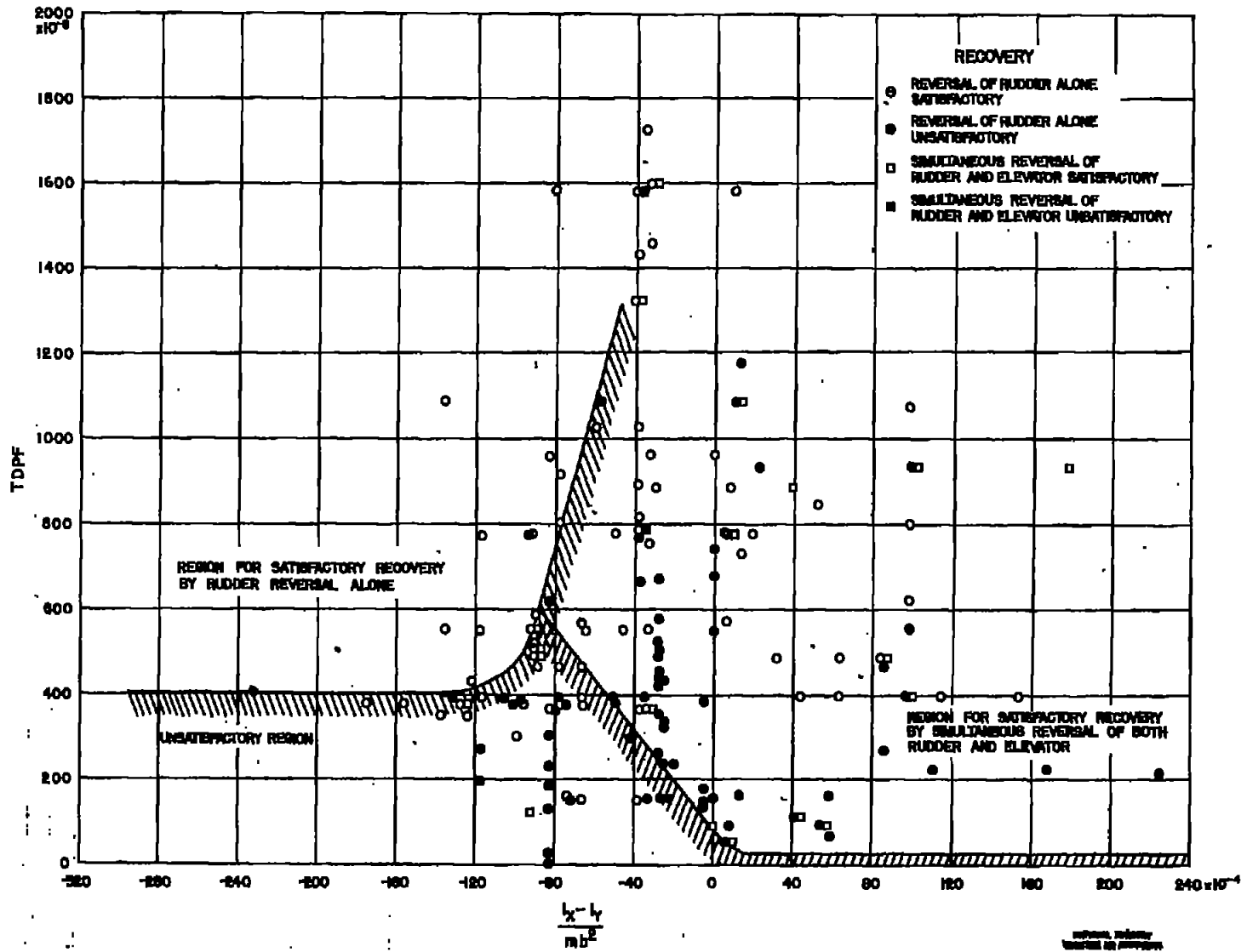


FIGURE 3—SPIN-RECOVERY DESIGN REQUIREMENTS FOR AIRPLANES WITH RELATIVE DENSITIES GREATER THAN 15 AND AS MUCH AS 20.

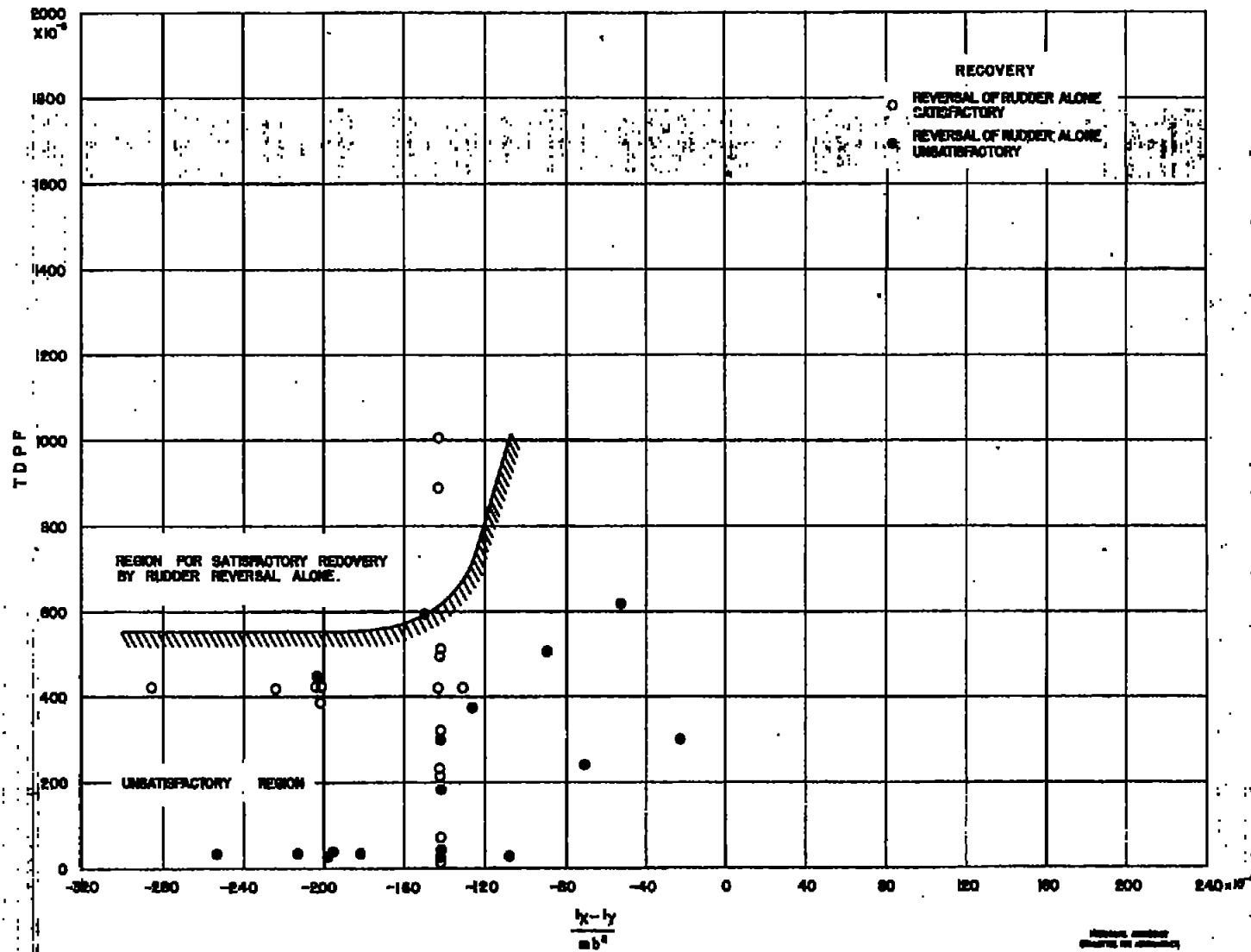


FIGURE 4.- SPIN-RECOVERY DESIGN REQUIREMENTS FOR AIRPLANES WITH RELATIVE DENSITIES GREATER THAN 20 AND AS MUCH AS 35.

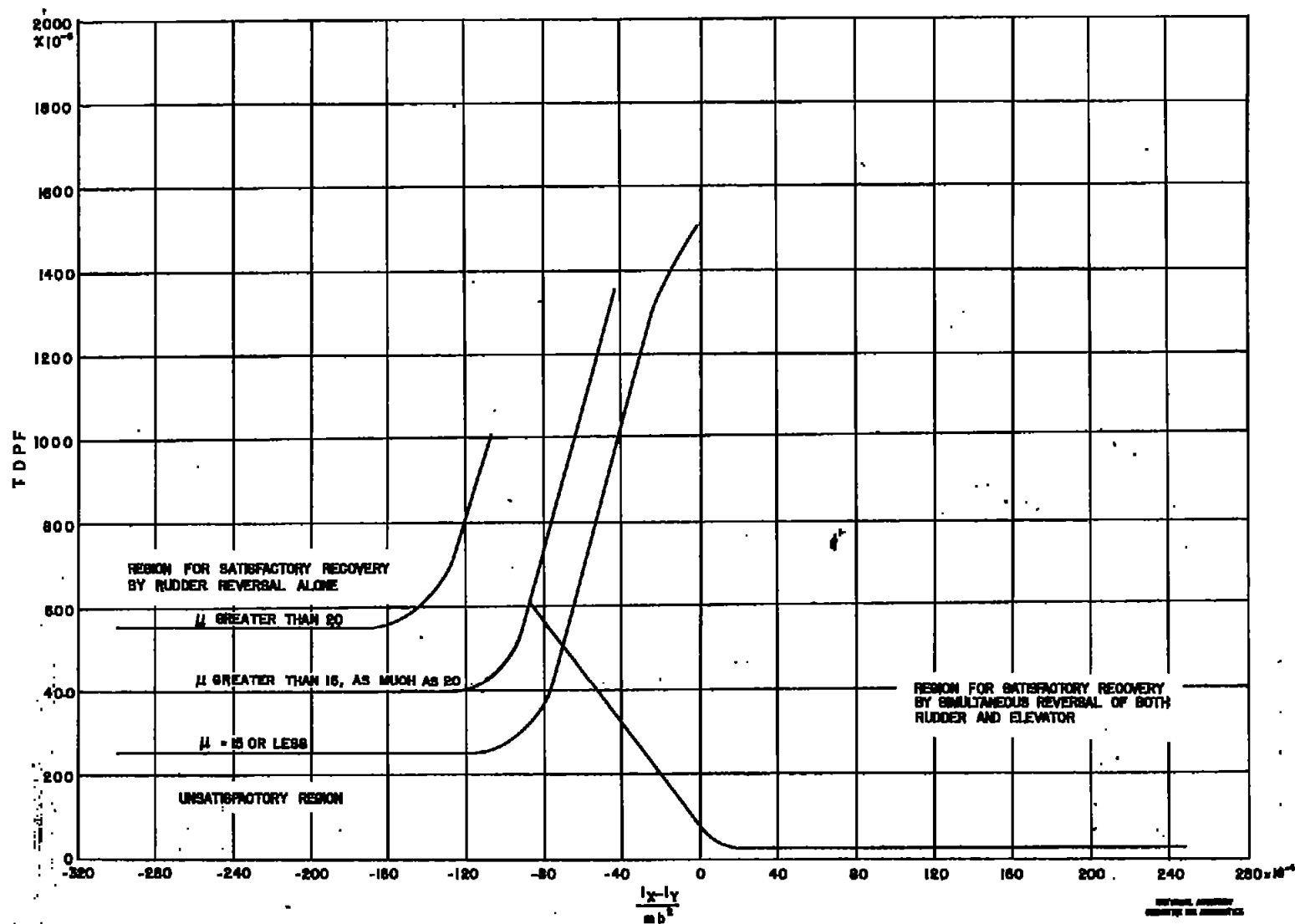


FIGURE 5.- COMPOSITE OF SPIN-RECOVERY DESIGN REQUIREMENTS FOR AIRPLANES WITH RELATIVE DENSITIES BETWEEN 0 AND 35.