REPORT No. 691

FREE-SPINNING WIND-TUNNEL TESTS OF A LOW-WING MONOPLANE WITH SYSTEMATIC CHANGES IN WINGS AND TAILS

V. EFFECT OF AIRPLANE RELATIVE DENSITY

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SUMMARY

The reported tests are a continuation of an N. A. C. A. investigation being made in the free-spinning wind tunnel to determine the effects of independent variations in load distribution, wing and tail arrangement, and control disposition on the spin characteristics of airplanes.

The standard series of tests was repeated to determine the effect of airplane relative density. Tests were made at values of the relative-density parameter of 6.8, 8.4 (basic), and 12.0; and the results were analyzed. The tested variations in the relative-density parameter may be considered either as variations in the wing loading of an airplane spun at a given altitude, with the radii of gyration kept constant, or as a variation of the altitude at which the spin takes place for a given airplane. The lower values of the relative-density parameter correspond to the lower wing loadings or to the lower altitudes of the spin.

For all tail and wing arrangements, the lower values of the relative-density parameter gave faster recoveries from steeper spins and the higher values gave slower recoveries from flatter spins than for the basic loading condition. In general, as the relative-density parameter decreased, the rate of vertical descent decreased, the spin coefficient $\Omega b/2V$ increased, and the sideslip became more outward. The importance of airplane relative density, wing arrangement, and control manipulation increased as the effectiveness of the tail unit decreased.

INTRODUCTION

The N. A. C. A. has undertaken a systematic investigation in the free-spinning wind tunnel to determine the effect of independent variations in mass and dimensional characteristics on the spin characteristics of airplanes.

The major wing variables include tip shape, airfoil section, plan form, and flaps. The Army standard tapered wing, also included in the test program, combines changes in plan form and thickness. The three tail arrangements range from a combination utilizing full-length rudder and raised stabilizer on a deep fuselage, designed to be extremely efficient in providing yawing moment for recovery, to a more nearly conventional type with the rudder completely above a shallow fuselage and almost completely shielded by the horizontal surfaces.

The results of tests of each of eight wings and three tails on a low-wing single-engine monoplane for a basic loading condition, representative of an average of values of 21 American airplanes for which the moments of inertia were available, were reported in reference 1. This model is still representative of recent single-engine airplanes. Results with weight distributed chiefly along the fuselage and with weight distributed chiefly along the wings are presented in references 2 and 3, respectively; the effect of center-of-gravity location is reported in reference 4. The present paper deals with the effect of the airplane relative density upon the spin of a representative single-engine monoplane.

As used in this paper, "airplane relative density" is defined as the ratio of the mass of an airplane to the mass of a volume of air, this volume being dependent upon the dimensions of the airplane but not necessarily being equal to the volume of the airplane. It is measured by the airplane relative-density parameter μ, which is defined as $W/g\rho Sb$, where W/g is the mass of the airplane, ρ is the density of the ambient air, S is the area of the wing, and b is the span of the wing.

In addition to tests for the basic loading condition with a value of the relative-density parameter of 8.4, tests were made with the relative-density parameter below (μ=6.8) and above (μ=12.0) the basic value. The radii of gyration and the center-of-gravity location were kept constant for the three loading conditions. Most of the present low-wing monoplanes that are comparable in size with the one represented by the tested model have values of relative density within the range of the tests.

The ratio $W/g\rho Sb$ may be varied by a change either in air density ρ or in airplane wing loading W/S. The results of tests may therefore be taken as indicative of the effect on spin characteristics of a variation in the wing loading (radii of gyration kept constant) of an airplane spun at a given altitude or of a variation in the altitude at which the spin for a given airplane takes place, the lower values of μ corresponding to the lower wing loadings or the lower altitudes of the spin, and vice versa.

APPARATUS AND METHODS

A general description of model construction and testing technique in the N. A. C. A. free-spinning tunnel is given in reference 5. The models are constructed of balsa, reinforced with spruce and bamboo. In order to reduce the weight, the fuselage and the wings are hollowed out, the external contours being maintained by silk tissue paper on reinforcing ribs. The desired load distribution is attained by suitable location of lead weights.

Figures 1 to 5 show special structural features of the model used in the present investigation. The wing and

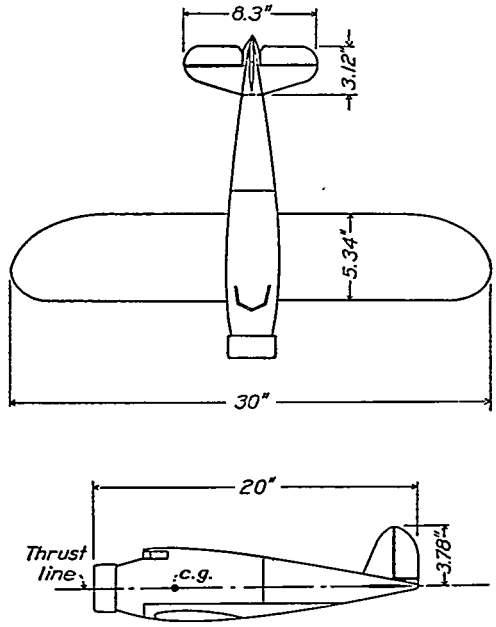
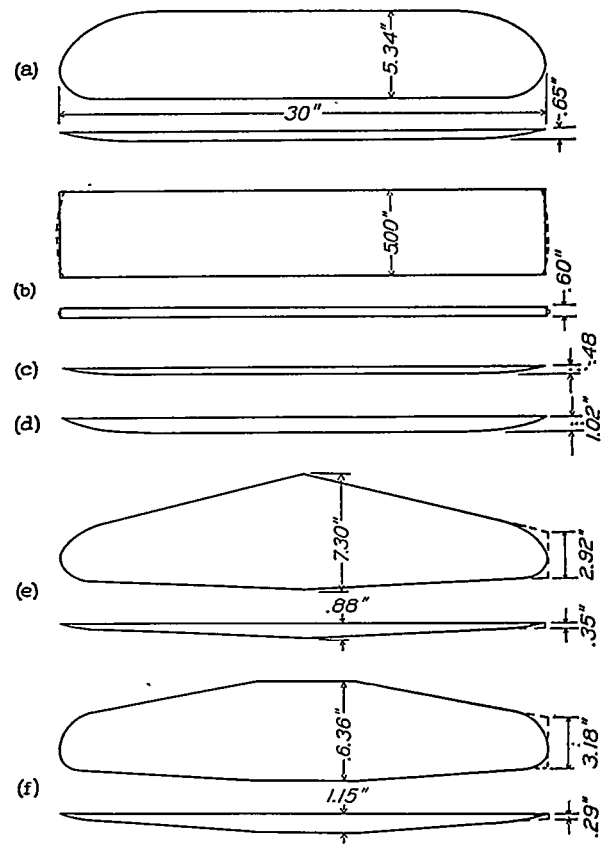


FIGURE 1.—Low-wing monoplane model with detachable tail and wing.

the tail units are independently removable and interchangeable to permit testing any combination. The exchange of units can be made without any change in mass distribution. The mass distribution can also be changed without changing the wing or the tail arrangement. A clockwork delay-action mechanism is installed to actuate the controls for recovery.

The model was not scaled from any particular airplane but was designed to be a representative low-wing cabin monoplane with a cowled radial engine and with landing gear retracted. Dimensional characteristics of the model and of the eight wings and the three tails are given on the line drawings of figures 1, 2, and 3. For convenience in making comparisons, the model may be considered to have the proportions of a 1/15-scale model of either a fighter or a four-place cabin airplane. The corresponding full-scale dimensional characteristics for the model for tail C would be:

Mean wing chord ($c=S/b$)	75 inches.
Span (b)	37.5 feet.
Wing area (S)	234.4 square feet.
Aspect ratio	6.
Distance from quarter-chord point to elevator hinge	16.6 feet.
Distance from quarter-chord point to rudder hinge	61.9 feet.
Fin area	6.8 square feet.
Rudder area	6.9 square feet.
Stabilizer area	19.8 square feet.
Elevator area	12.9 square feet.
Control travel	Rudder: ±30°. Elevator: 30° up. 20° down.



(a) Wing 1—23012 rectangular with Army tips; wing 2—23012 with 20-percent full-span split flaps at 60°.
(b) Wing 3—23012 rectangular with rectangular tips; wing 4—23012 rectangular with faired tips.
(c) Wing 5—0009 rectangular with Army tips (plan same as wing 1).
(d) Wing 6—6718 rectangular with Army tips (plan same as wing 1).
(e) Wing 7—23012 5:2 taper with Army tips.
(f) Wing 8—23018-09 standard Army wing (2:1 taper, square center, Army tips)

FIGURE 2.—Wings used on low-wing monoplane. N. A. C. A. wing sections.

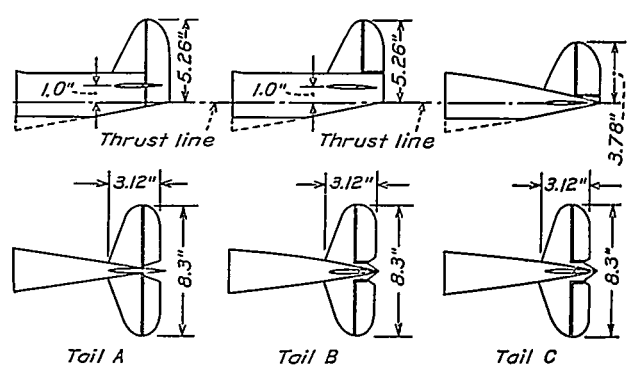
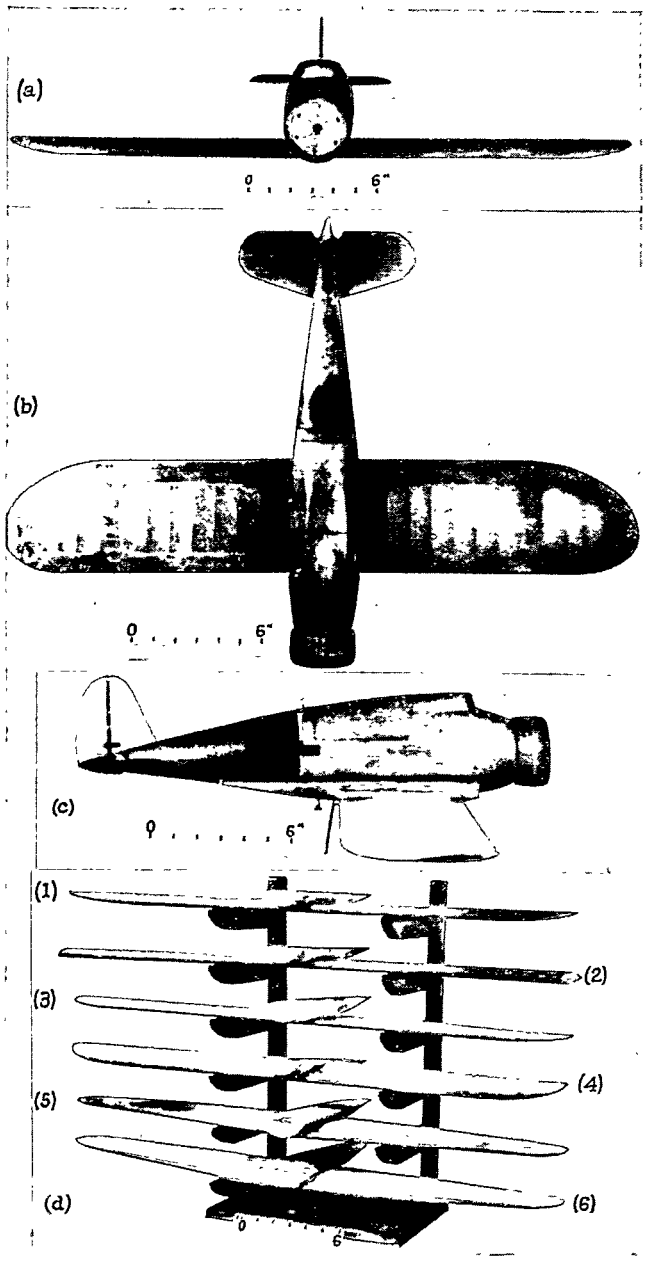


FIGURE 3.—Tails used on low-wing monoplane.

The corresponding full-scale mass characteristics for the present tests may be considered, as previously mentioned, either on the basis of (1) a variation in the wing loading of an airplane spun at a given altitude, or (2) a variation in the altitude at which the spin for an airplane with a given wing loading takes place.

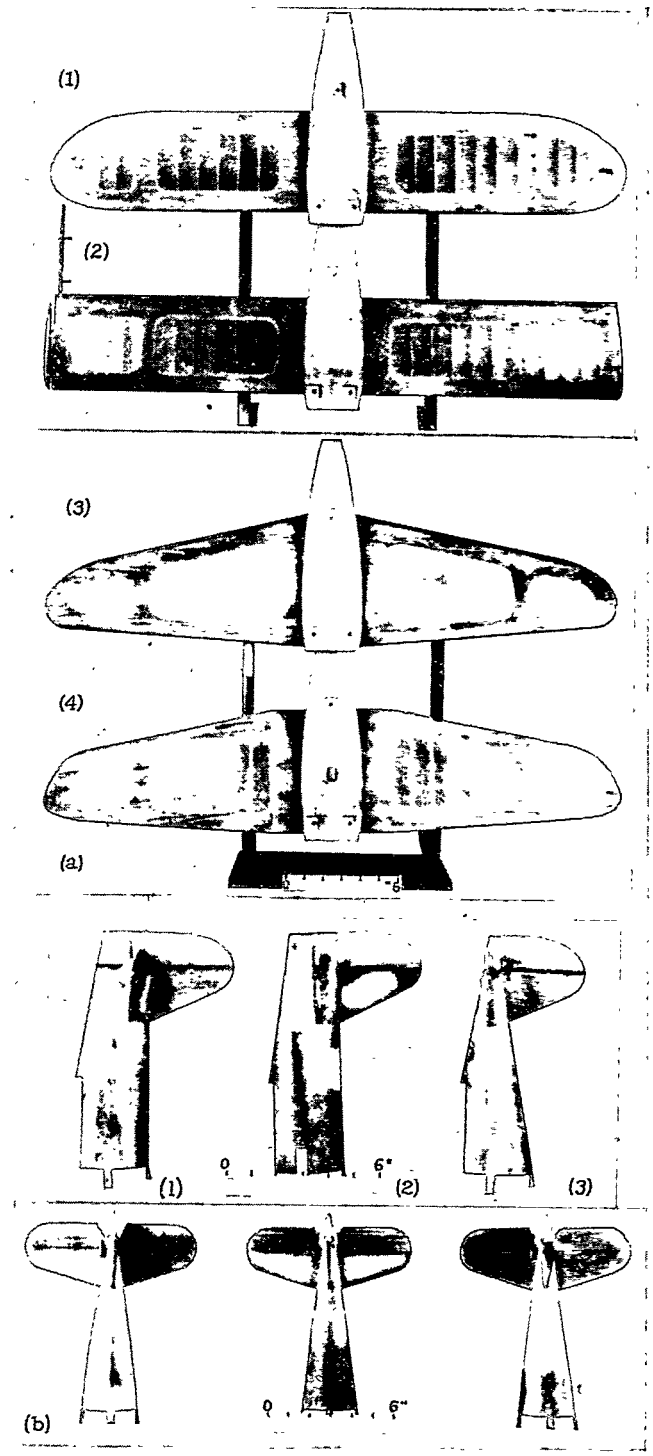


(a) Front view.
(b) Plan view.
(c) Side view, showing detachable parts.
(d) Low-wing monoplane wings: (1) Wings 1 and 2; (2) wings 3 and 4; (3) wing 5; (4) wing 6; (5) wing 7; (6) wing 8.

FIGURE 4.—Low-wing monoplane model.

(1) For a variation in the wing loading, for an altitude of 6,000 feet (ρ=0.001988), the mass characteristics are:

Relative-density parameter $\left(\mu=\frac{W}{g\rho Sb}\right)$	6. 8	8. 4	12. 0
Wing loading, pounds per square foot	16. 4	20. 1	28. 8
Weight, pounds	3, 840	4, 720	6, 750
Principal moments of inertia, slug-feet ^{2}:			
$A=mk_X^2$	2, 250	2, 760	3, 950
$B=mk_Y^2$	3, 230	3, 970	5, 680
$C=mk_Z^2$	5, 000	6, 150	8, 800



(a) (1) Rectangular wing with Army tips; (2) rectangular wing with interchangeable rectangular and faired tips; (3) 5:2 tapered wing with Army tips; (4) 2:1 Army standard tapered wing with square center.
(b) (1) Tail A, deep fuselage and long rudder; (2) tail B, deep fuselage and short rudder; (3) Tail C, shallow fuselage and short rudder.

FIGURE 5.—Interchangeable wings and tails of low-wing monoplane model.

For the airplane with the foregoing wing loadings, the values of the relative-density parameter μ at sea level (ρ=0.002378) would be 5.7, 7.0, and 10.0, respectively. Previous reports of this series describe the loading condition of the airplane by means of the relative-density parameter as determined at sea level. For the present report, it was considered desirable to use the values of μ at the actual spin altitude.

(2) For a variation in the spin altitude for a wing loading of 20.1 pounds per square foot (weight=4,720 pounds, A=2,760, B=3,970, C=6,150 slug-feet^2), the equivalent spin altitudes are:

Relative-density parameter μ	6.8	8.4	12.0
Approximate spin altitude, feet	Sea level	6,000	17,000

The moments of inertia A, B, and C and the radii of gyration k_X, k_Y, and k_Z are about the X, Y, and Z axes, respectively.

The nondimensional mass-distribution parameters for the three relative-density loadings are:

Pitching-moment inertia parameter $[Wb^2/g(C-A)]$	61
Rolling-moment and yawing-moment inertia parameter:	
$[(C-B)/(C-A)]$	.64
b/k_X	8.7
x/c	.25
z/c	0

where the symbols are defined as follows:

x distance of center of gravity back of leading edge of mean chord.
z distance of center of gravity below thrust line.
c mean wing chord.

Figures 1 and 4 show the model with the basic wing (wing 1) and tail C installed. This wing is of N. A. C. A. 23012 section with rectangular plan form and Army tips. (The tip contour is derived as described in reference 6.) In common with the other wings, it has an area of 150 square inches, a span of 30 inches, and no dihedral, twist, or sweepback.

The other seven wings (figs. 2 and 5) have varied dimensional characteristics as follows:

Wing 2: N. A. C. A. 23012 section, rectangular with Army tips, 20-percent-chord split flaps deflected 60°.

Wing 3: N. A. C. A. 23012 section, rectangular with rectangular tips.

Wing 4: N. A. C. A. 23012 section, rectangular with faired tips.

Wing 5: N.A.C.A. 0009 section, rectangular with Army tips.

Wing 6: N. A. C. A. 6718 section, rectangular with Army tips.

Wing 7: N. A. C. A. 23012 section, 5:2 taper with Army tips.

Wing 8: N. A. C. A. 23018–09 section, Army standard plan form (square center section, 2:1 taper in both plan form and thickness, and Army tips).

Each wing is mounted on the model at an angle of incidence equal to the angle of zero lift for the particular section. The stabilizer is set at zero incidence for each tail. There is no fin offset.

The three tails designated A, B, and C are shown in figures 3 and 5. Tail C, representing a conventional shallow fuselage with rudder completely above the tail cone, has the following dimensional characteristics:

Vertical tail area: 6 percent wing area (3 percent rudder and 3 percent fin).

Fuselage side area, back of leading edge of stabilizer: 2 percent wing area.

Vertical tail length, from wing quarter-chord point to rudder hinge axis: 45 percent wing span.

Horizontal tail area: 14 percent wing area (5.5 percent elevator and 8.5 percent stabilizer).

Horizontal tail length, from wing quarter-chord point to elevator hinge axis: 44 percent wing span.

Tail B was derived from tail C by increasing the fuselage depth, raising the stabilizer and the elevators, and installing approximately the original fin and rudder atop the deepened fuselage. For tail B, the vertical areas are:

Vertical tail area: 6 percent wing area.

Fuselage side area back of leading edge of stabilizer: 5.5 percent wing area.

Tail A is similar to tail B except for full-length rudder construction and slightly increased elevator cut-out. For tail A, the vertical areas are:

Vertical tail area: 8 percent wing area (5 percent rudder and 3 percent fin).

Fuselage side area back of leading edge of stabilizer: 3.4 percent wing area.

TESTS AND RESULTS

For each wing and tail combination with each value of the relative-density parameter, spin tests were made for four control settings:

(a) Rudder 30° with the spin, elevators neutral.
(b) Rudder 30° with the spin, elevators 20° down.
(c) Rudder 30° with the spin, elevators 30° up.
(d) Rudder neutral, elevators neutral.

Recovery from (a) and (b) was attempted by reversal of the rudder, from (c) by complete reversal of both controls as well as by reversal of the rudder alone, and from (d) by moving the rudder full against the spin and the elevators full down.

The angle of attack α, the angle of sideslip β, the rate of descent V, the spin coefficient $\Omega b/2V$ (where Ω is the angular velocity), and the turns for recovery are plotted in 12 charts (figs. 6 to 17), grouped so as to permit ready comparison of the effects of relative density, tip shape, plan form, section, flaps, and Army standard wing.

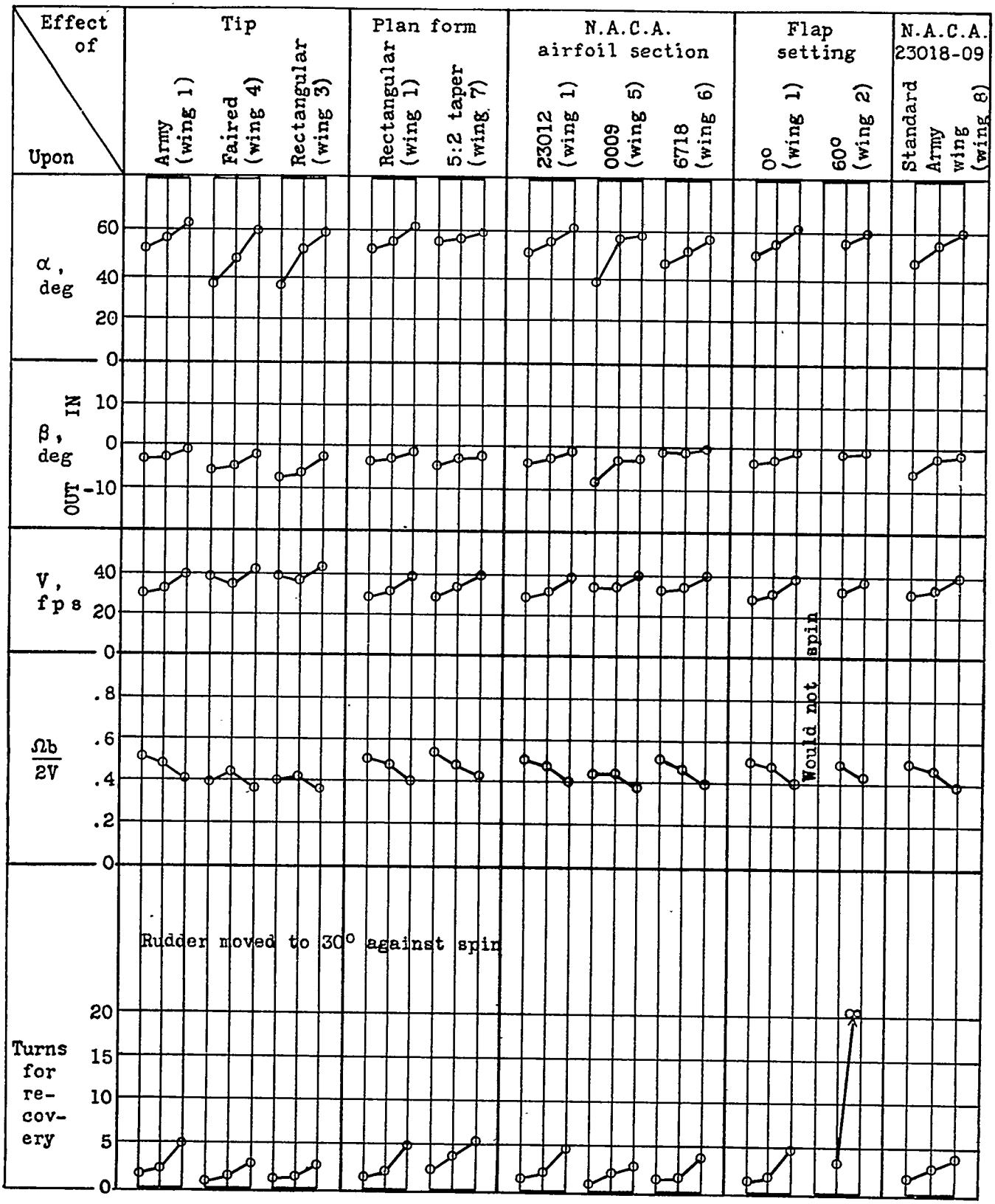


FIGURE 6.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted left to right; tail A; rudder 30° with; elevators 0°.

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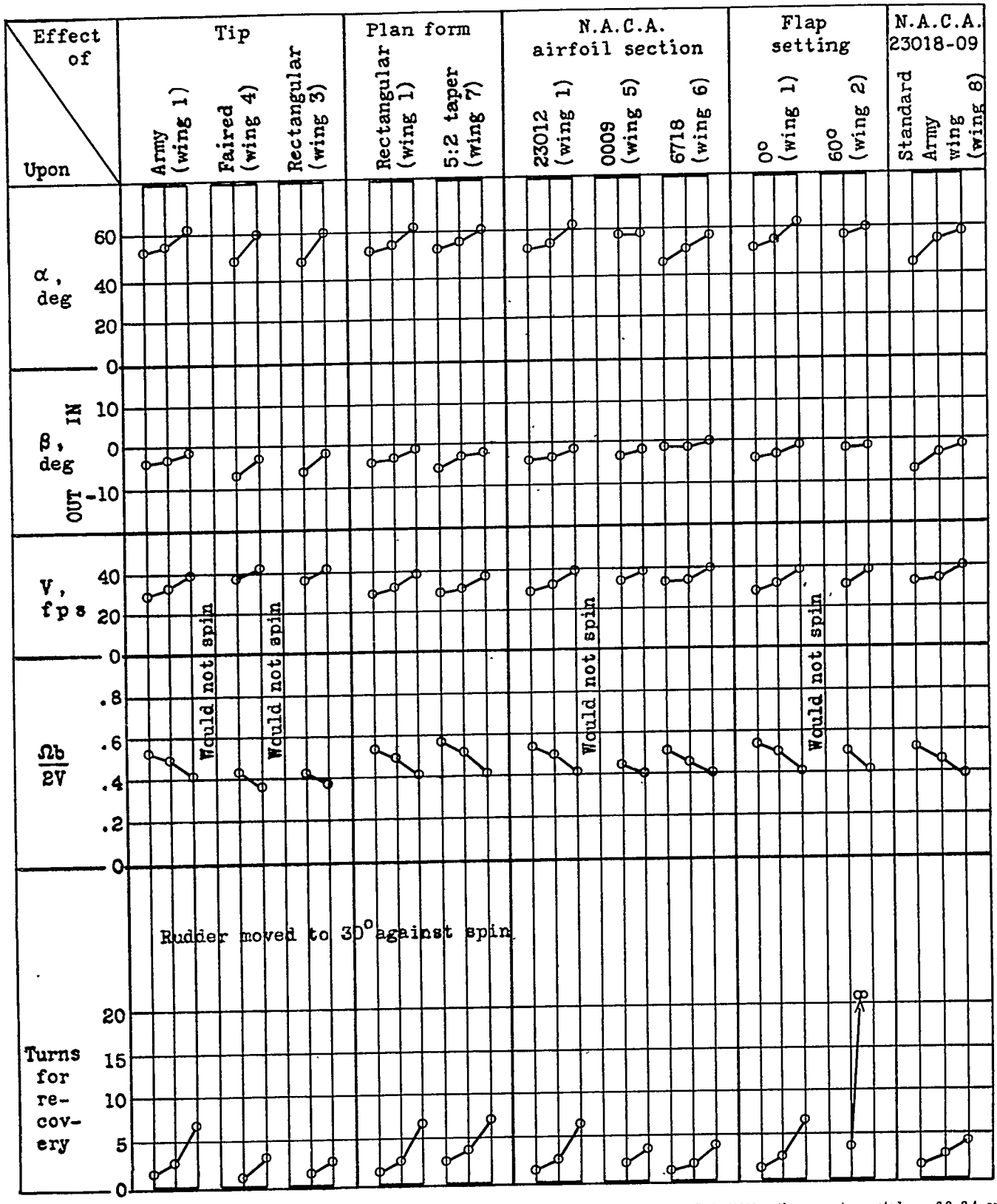

FIGURE 7.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted left to right; tail A; rudder 30° with; elevators 20° down.

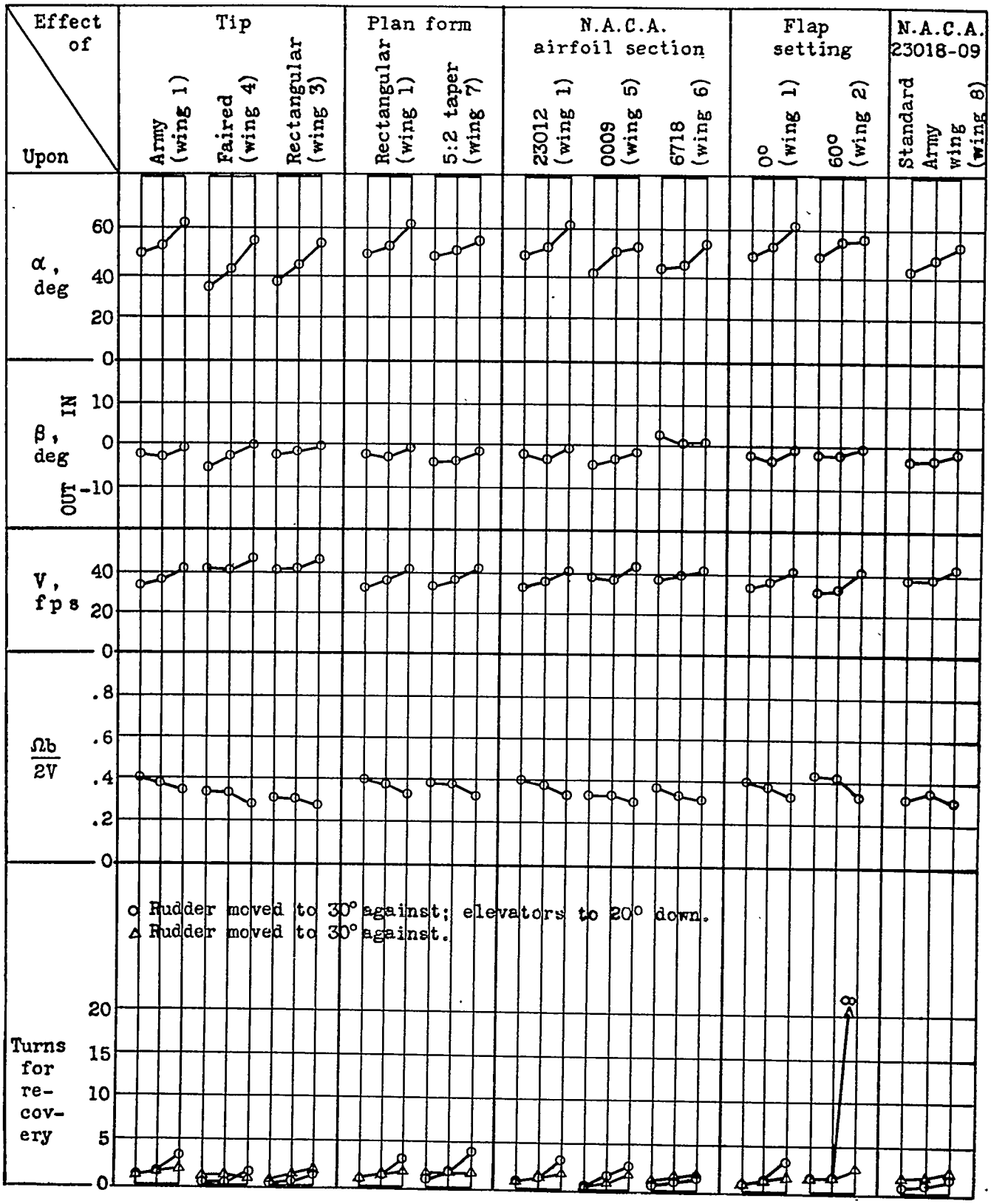

FIGURE 8.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail A; rudder 30° with; elevators 30° up.

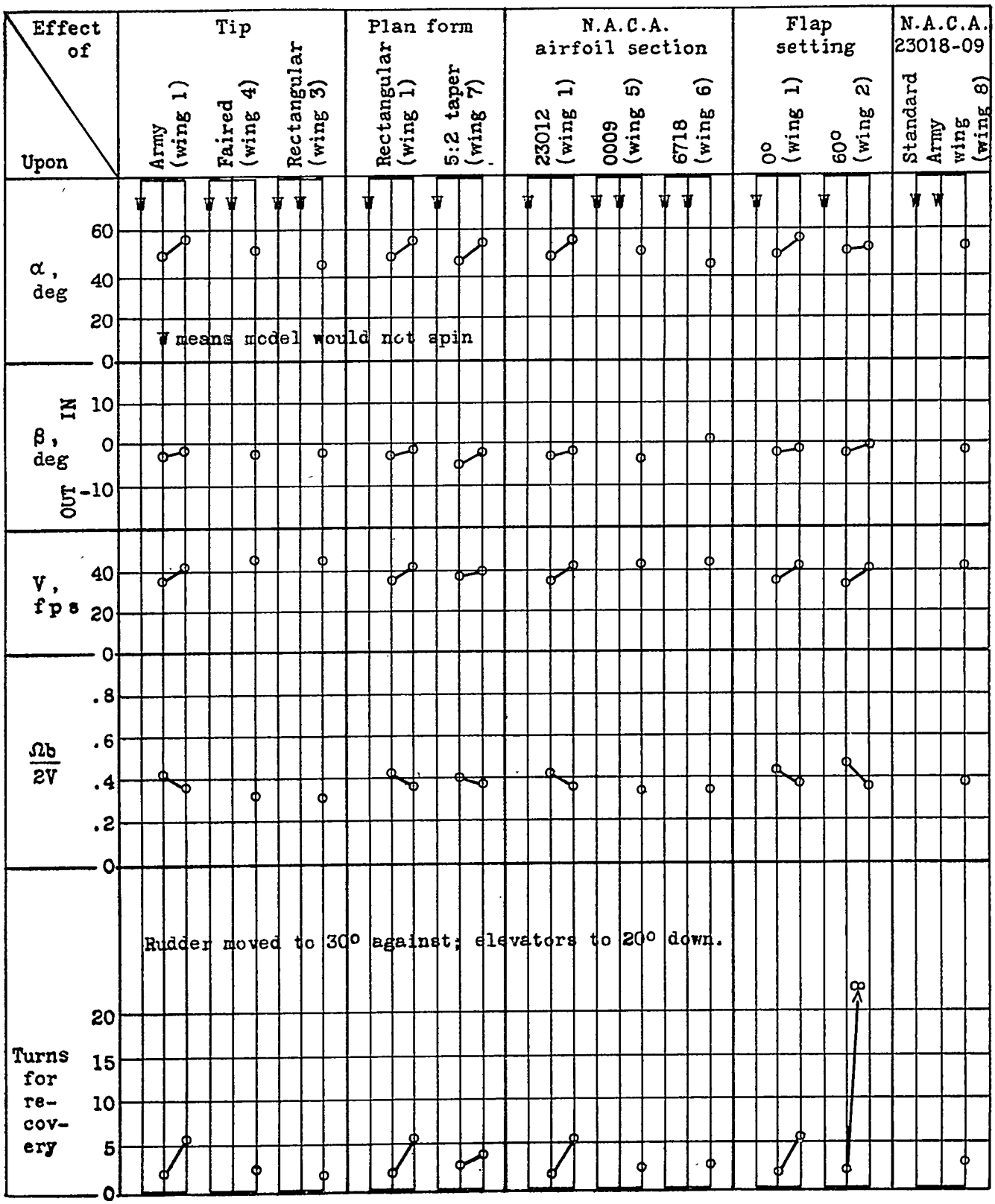

FIGURE 9.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail A; rudder 0°; elevators 0°.

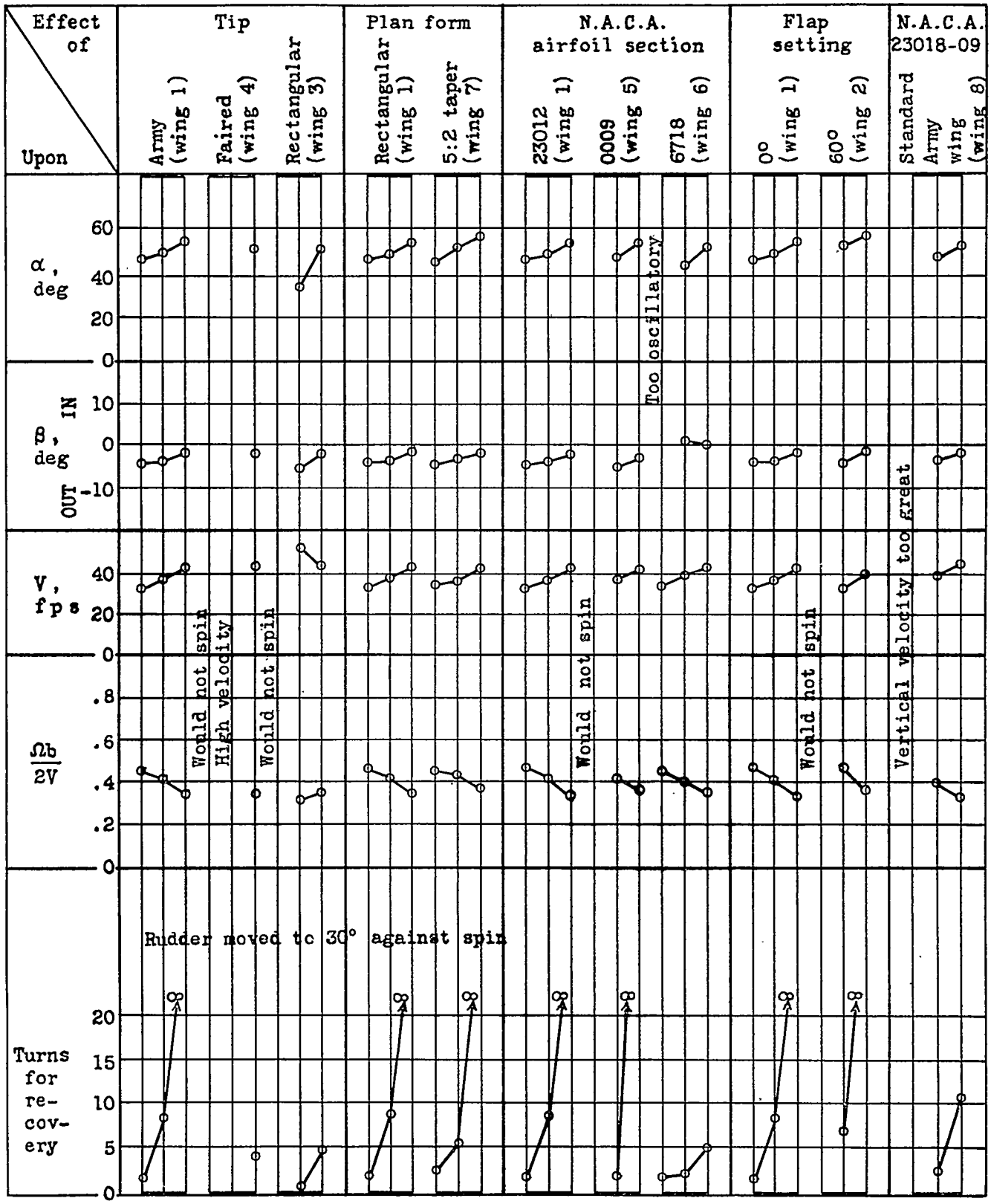

FIGURE 10.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail B; rudder 30° with; elevators 0°.

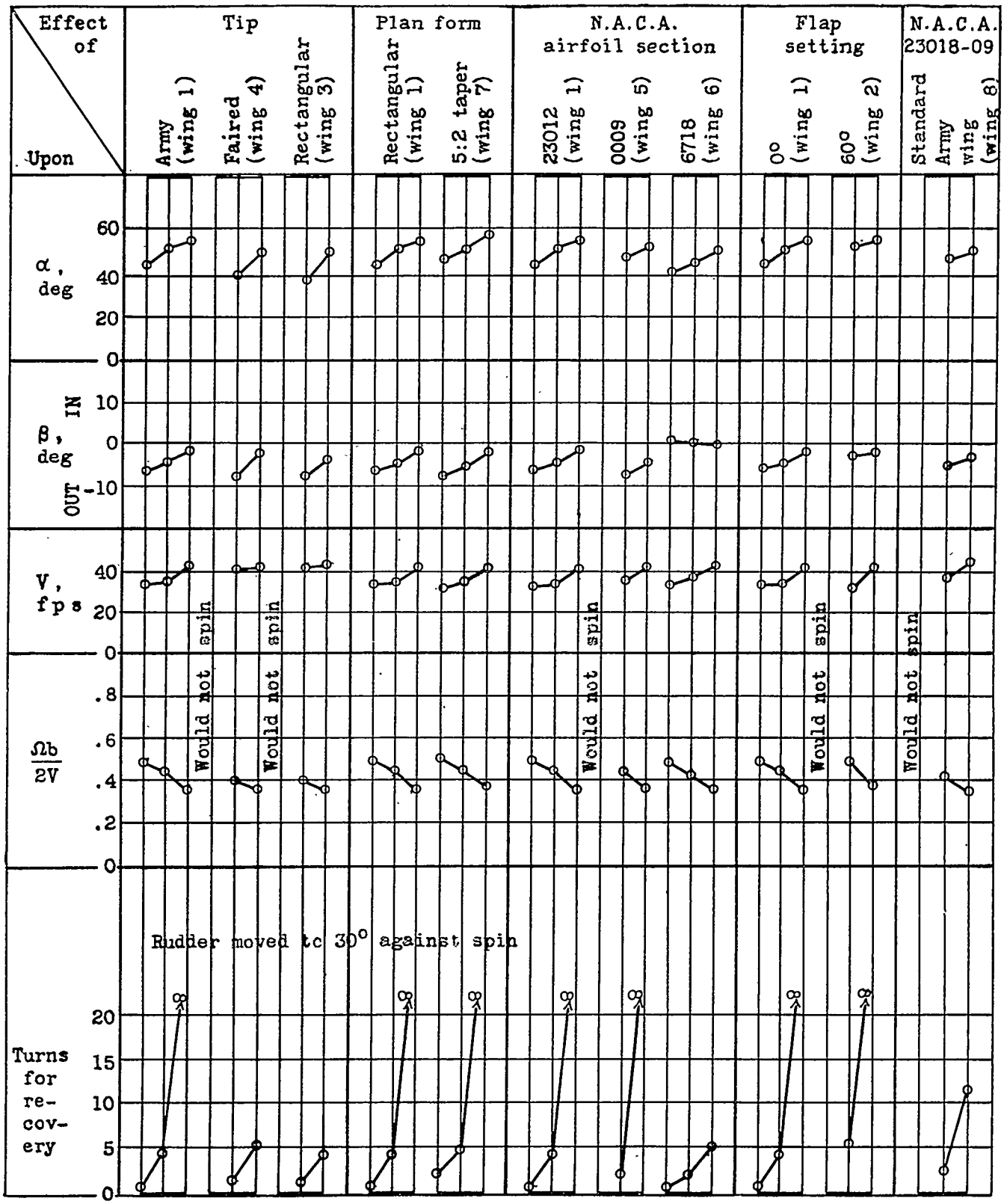

FIGURE 11.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail B; rudder 30° with; elevators 20° down.

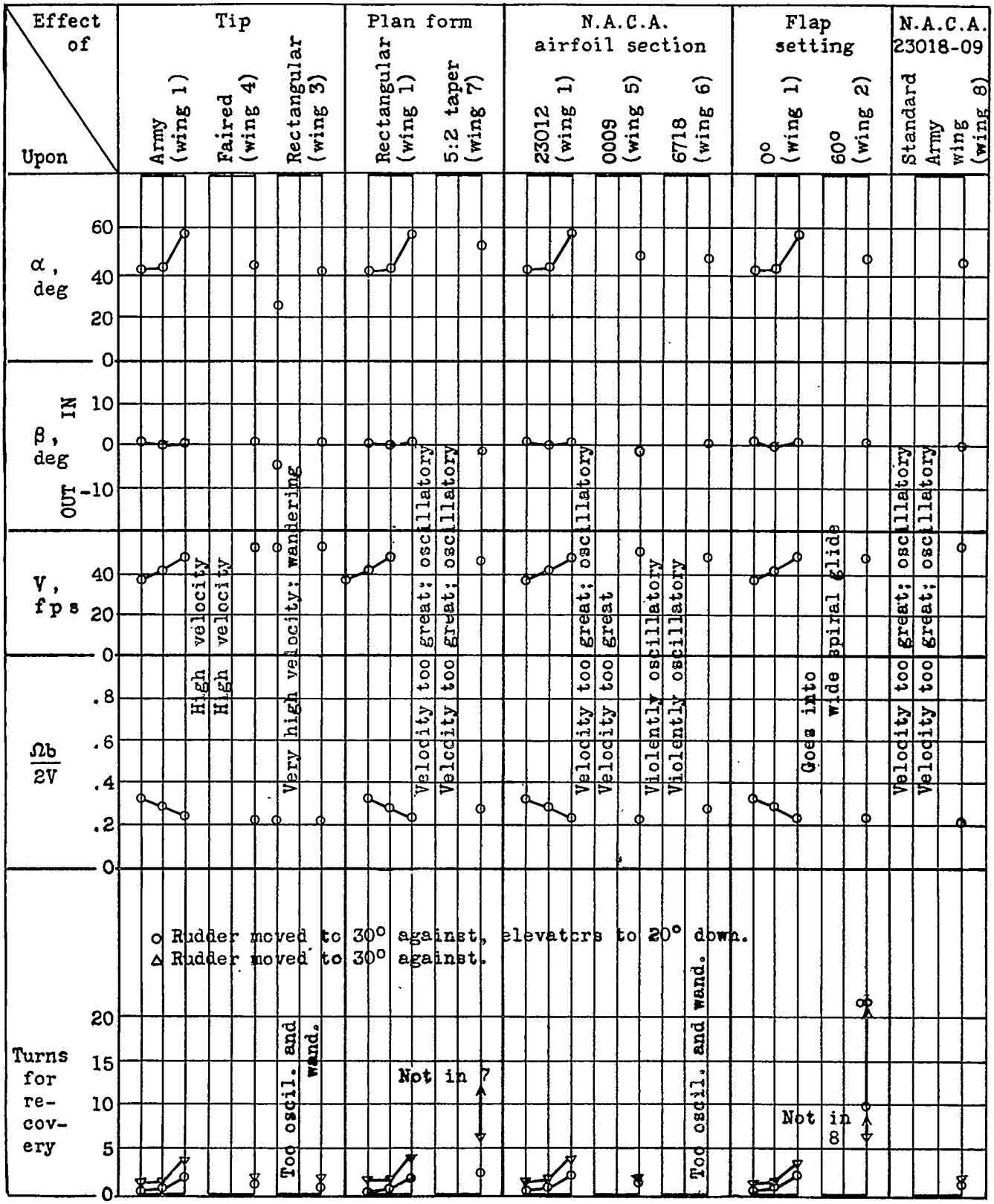

FIGURE 12.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail B; rudder 30° with; elevators 30° up.

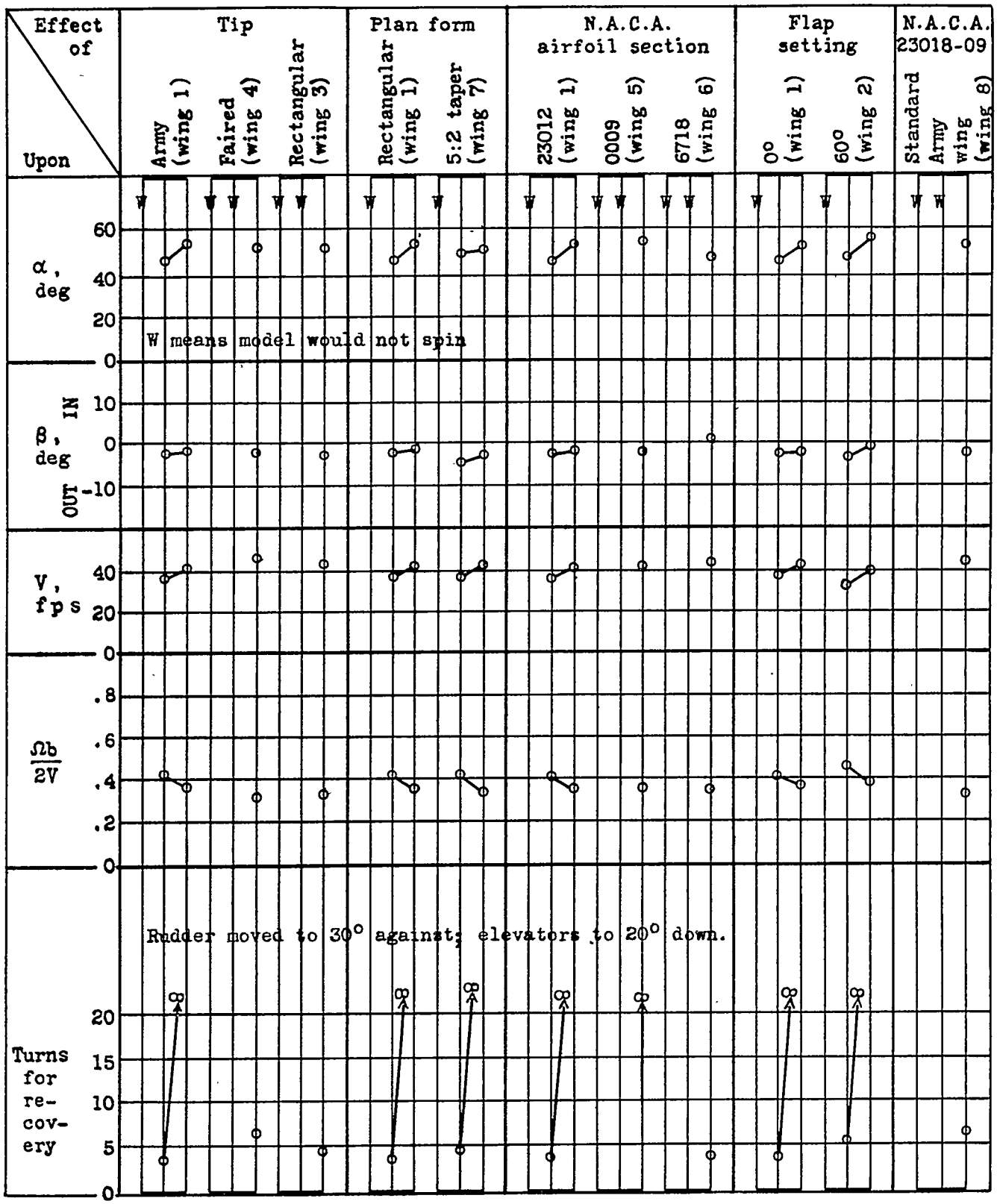

FIGURE 13.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail B; rudder 0°; elevators 0°.

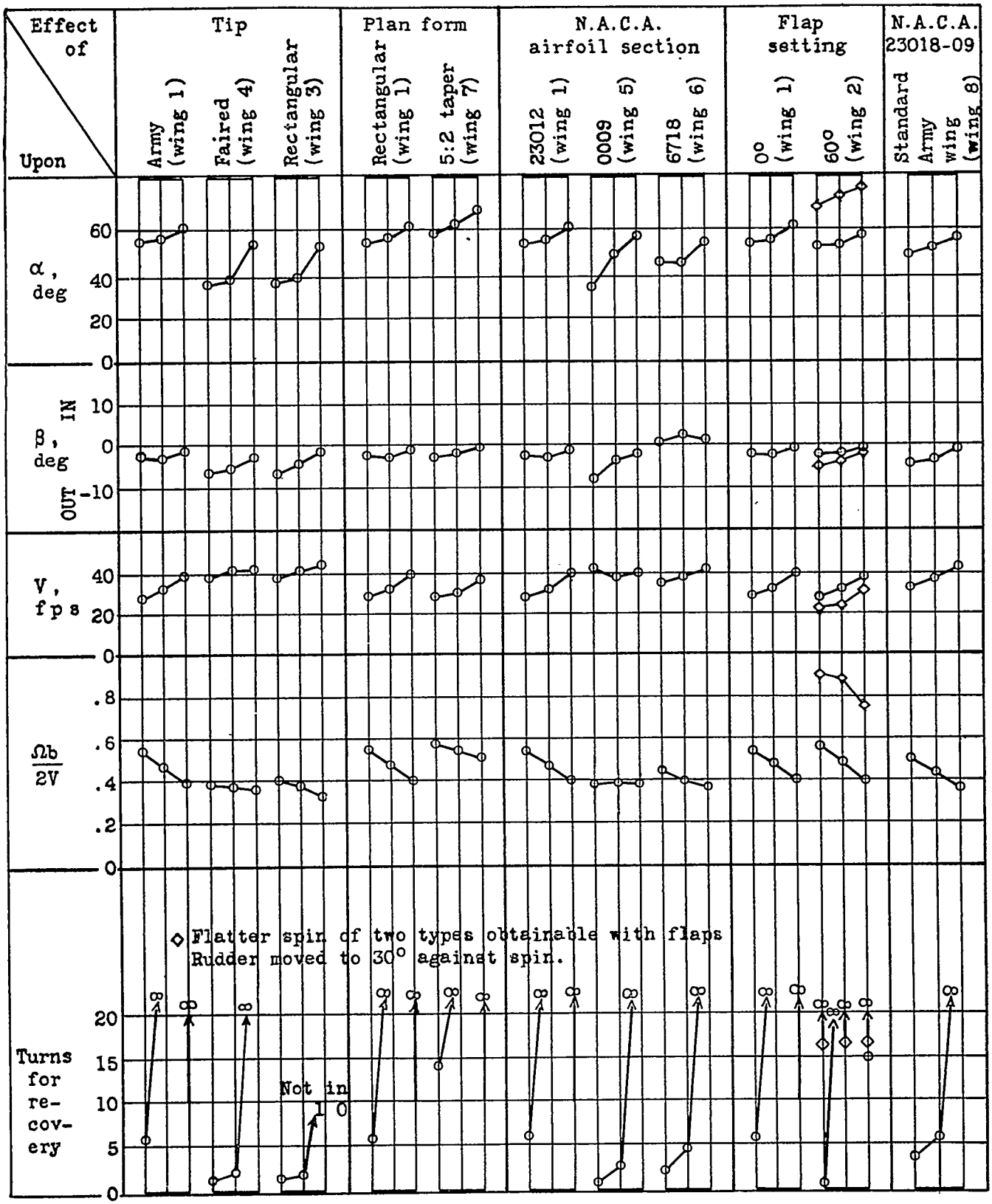

FIGURE 14.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail C; rudder 30° with; elevators 0°.

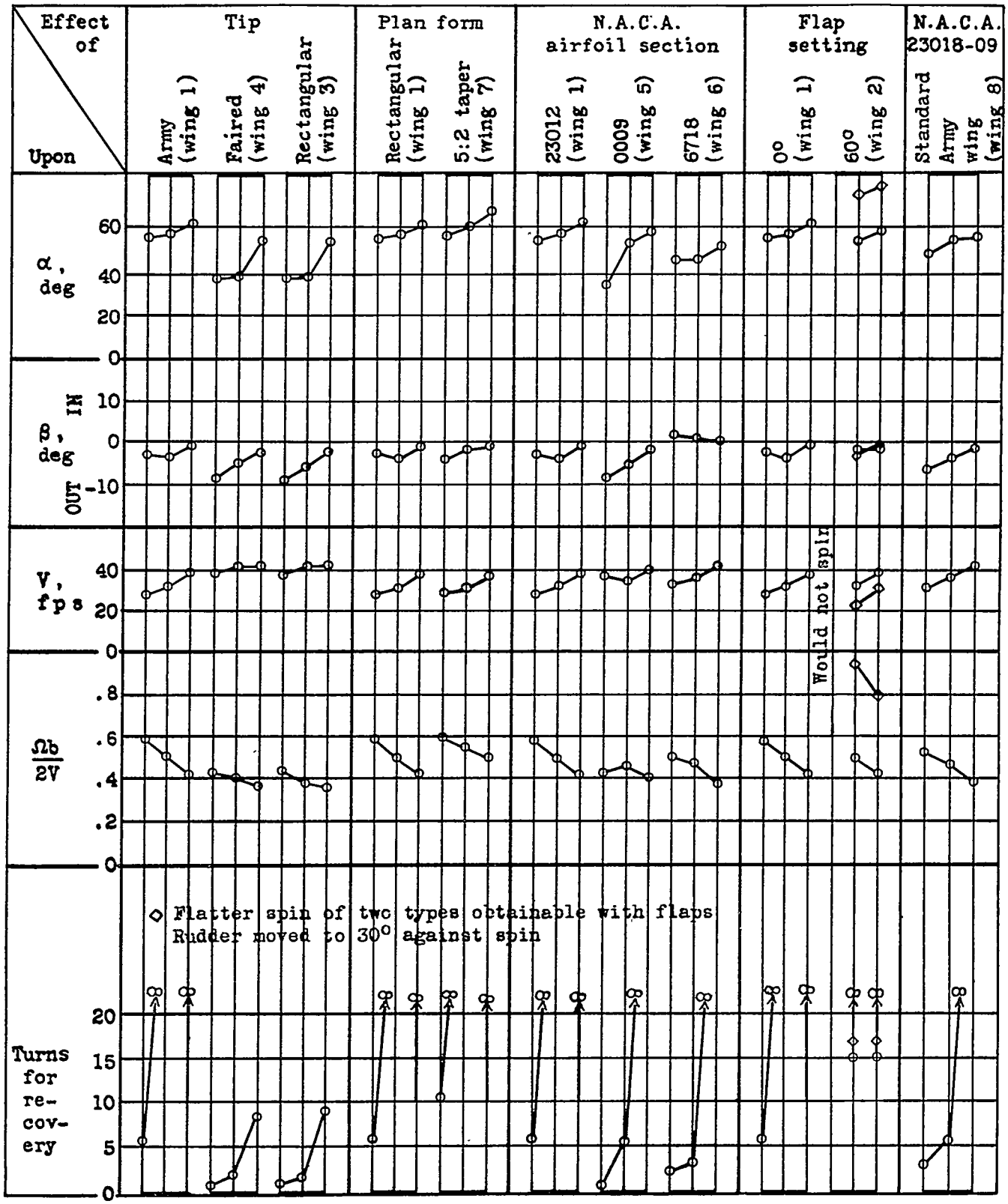

FIGURE 15.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail C; rudder 30° with; elevators 20° down.

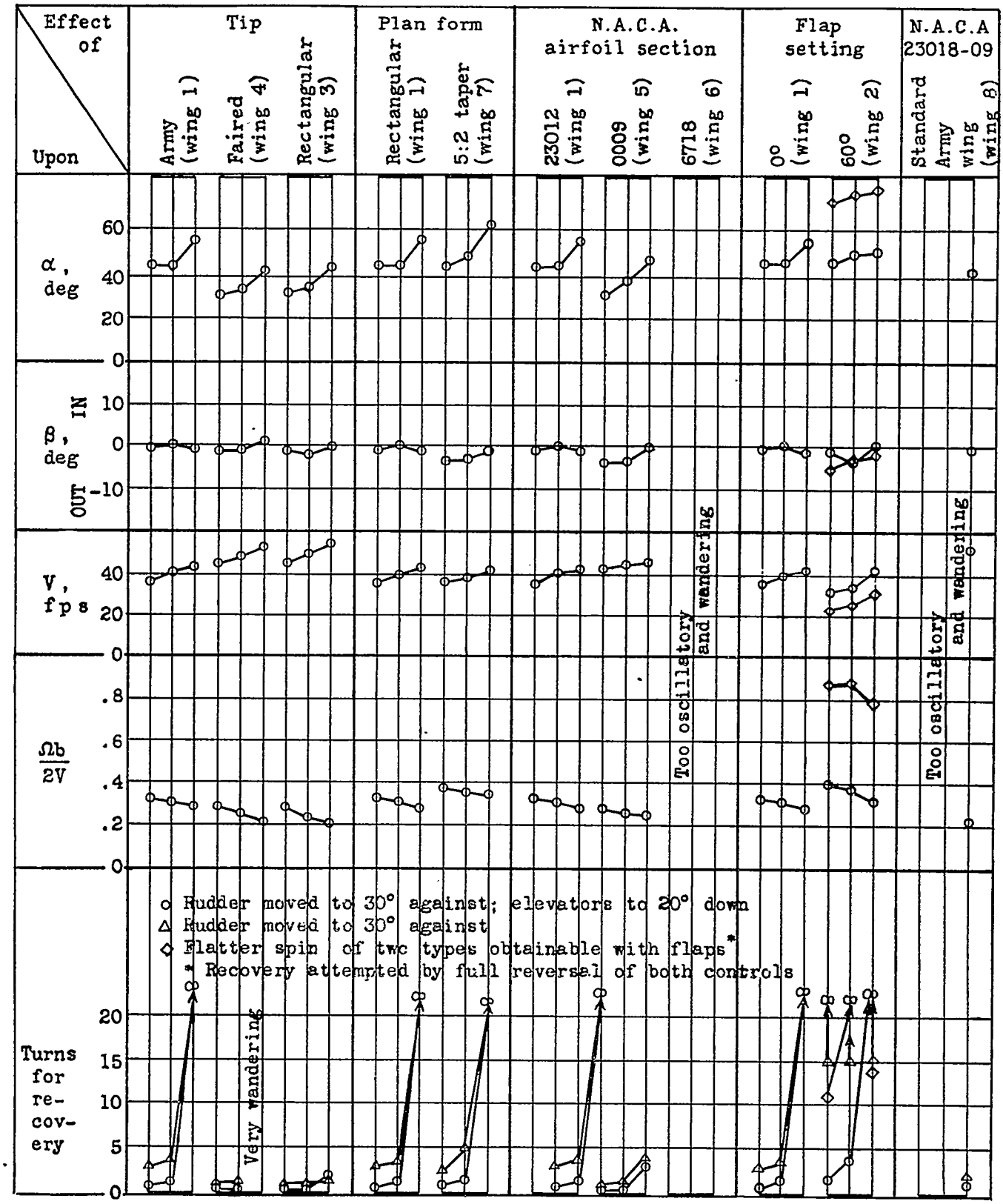

FIGURE 16.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail C; rudder 30° with; elevators 30° up.

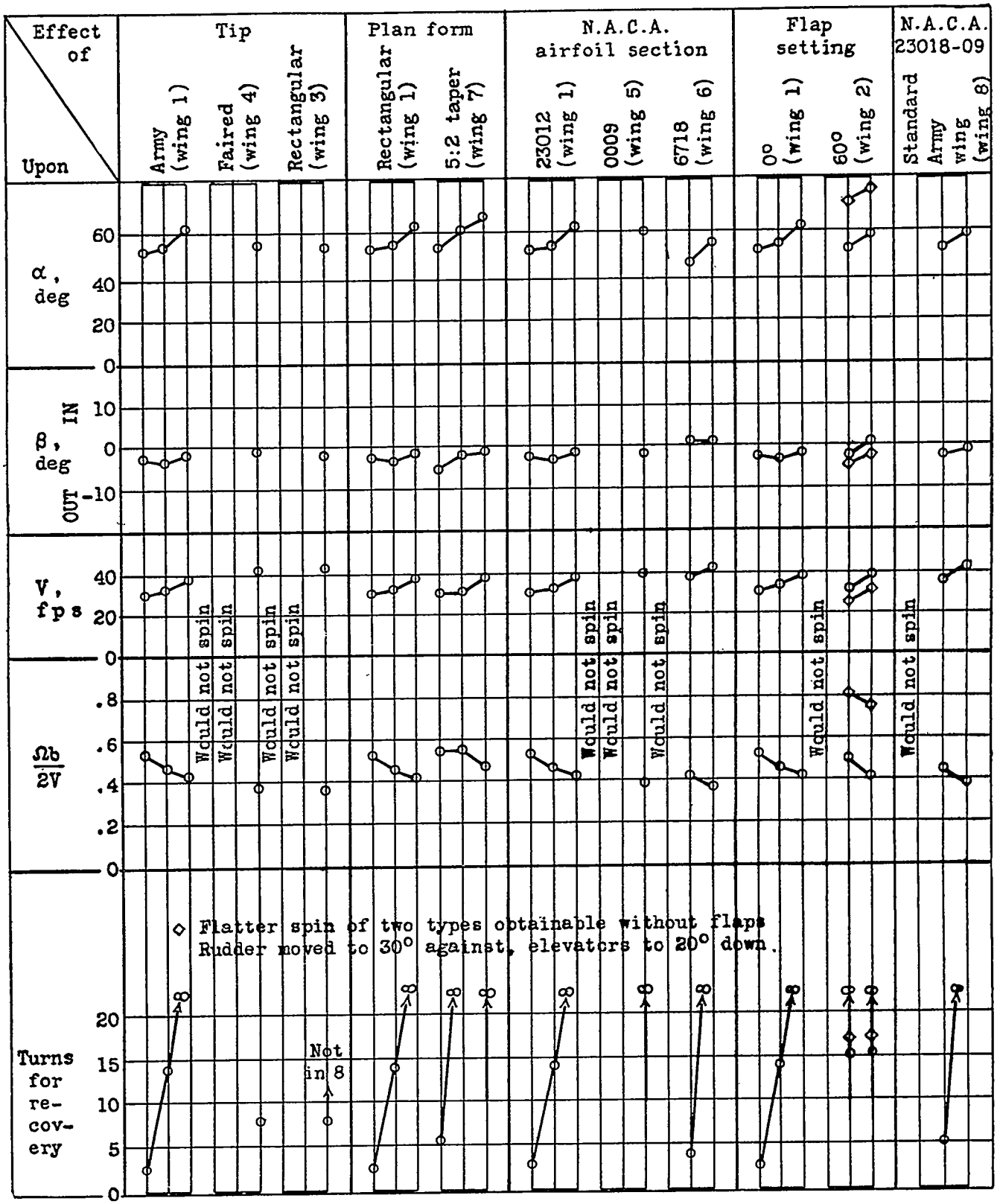

FIGURE 17.—The effect of various wings on the spin characteristics. Wing has rectangular plan form, Army tips, N. A. C. A. 23012 section, except as noted. μ=6.8, 8.4, and 12.0, plotted from left to right; tail C; rudder 0°; elevators 0°.

The data on these charts are believed to represent the true model values within the following limits (see reference 5):

α	$\pm 3°$.
β	$\pm 1\frac{1}{2}°$.
Turns for recovery	$\pm \frac{1}{4}$ turn.
$\Omega b/2V$	± 3 percent.
V	± 2 percent.

For certain isolated spins in which it was difficult to control the model in the tunnel owing to high air speed or to wandering or oscillatory motion, the foregoing limits may be exceeded.

DISCUSSION

As noted in reference 5, variations have been observed between model spin-test results and corresponding full-scale spin-test results for a given airplane, probably because of the difference of the Reynolds Number between the tests.

Before the results are discussed, some remarks on the spin parameters given in figures 6 to 17 appear desirable. The basic parameter is the number of turns for recovery and is, from the viewpoint of the pilot, of the most interest. The other parameters, the angle of attack, the angle of sideslip, the rate of descent, and the coefficient $\Omega b/2V$, define the steady spin prior to the recovery attempt. The steady-spin parameters and their correlation with the turns for recovery are of considerable importance from research considerations.

Extensive tests in the spin tunnel have repeatedly indicated that, for any given tail arrangement, the number of turns required for recovery will be the least from the steepest spins (lowest angle of attack). Load distributions, wing arrangements, and control dispositions that tend to steepen the spin will therefore have a favorable effect upon the recovery characteristics. The statement that steeper spins are associated with quicker recoveries should be considered to apply only to spins of a given airplane. When a comparison of the spins of two different airplanes is made, however, the airplane with the steeper spin may give the slower recovery. Results in the spin tunnel, for example, indicate that, in a change from a short-length rudder like tail B to a full-length rudder like tail A, there is a tendency toward a more rapid recovery although the spin is flatter with the full-length rudder. This result merely emphasizes the importance of a powerful rudder control for recovery.

The angle of sideslip in a spin affects the direction of air flow around the tail of an airplane and may therefore be of importance in determining the speed of recovery from a given spin. The angle of inclination of the wings to the horizontal, upon which the sideslip angle β depends, is a factor involved in determination of the inertia moments acting in a spin. The rate of vertical descent V is of importance in considerations involving the vertical distance available for effecting recovery from a spin, and the spin parameter $\Omega b/2V$ may be used to determine the angle of attack along the span of an airplane in a spin.

Tests with tail A (figs. 6 to 9).—Figures 6, 7, and 8 give results for rudder with the spin for different elevator settings. Results of spins with controls neutral are presented in figure 9. As previously stated, recovery was attempted by full rudder reversal alone when the elevators were down or neutral, by simultaneous reversal of both controls and by full rudder reversal alone when the elevators were up, and by moving the rudder to full against the spin and the elevators to full down when both controls were neutral.

The results indicate that decrease in the relative density will lead to faster recoveries; whereas, an increase in the relative density leads to slower recoveries. The turns for recovery, at the high value of the relative-density parameter, varied between wide limits for different wings. At the low value of μ, on the other hand, recoveries were very satisfactory for all wings for all control manipulations. It therefore follows that, as the wing loading of an airplane is decreased (radii of gyration being kept constant) or as the altitude of the spin is decreased, the recovery characteristics of the airplane will be improved.

The effect of relative density on the steady spin was to decrease the angle of attack with a decrease in the value of the relative-density parameter for all wings at all control settings. For the low value of μ with the elevators neutral, the angle of attack decreased so much that the wing with flaps deflected (wing 2) would not spin and, when the elevators were down, the nose-down tendency increased sufficiently to put the model out of the autorotation range for wings 2, 3, 4, and 5.

Except for the wing of N. A. C. A. 6718 section, outward sideslip generally increased as the relative density decreased. This result is in qualitative agreement with results obtained on the spin balance for several of the monoplane wings tested, which indicated that, as the relative density is decreased, the sideslip necessary for equilibrium in a spin generally becomes more outward (reference 7).

The rate of vertical descent V generally became slower and the spin coefficient $\Omega b/2V$ generally became larger as the relative density decreased even though the spins were steeper. For wings 2, 3, 4, and 5, the rate of descent became slower and the value of $\Omega b/2V$ became greater at first with a decrease in the relative density; but, as the spin became very steep, the rate of descent tended to become faster and the value of $\Omega b/2V$ to become less. The rate of vertical descent V depends upon the drag coefficient and the weight of the model, and it actually became faster even though the weight of the model had been diminished because the accompanying decrease in drag coefficient due to a smaller angle of attack predominated. The present results indicate that the angular velocity Ω was not much affected by variations in μ.

For the present tests, the effect of wing variables was very similar to the results obtained with center-of-gravity variations, as reported in reference 4. As before, the wings with rectangular and faired tips gave the steepest spins, the most outward sideslip, and the most rapid recoveries. The rectangular wing with Army tips consistently gave flatter spins and slower recoveries. Even slower recoveries were obtained for the wing of 5:2 taper with Army tips. The wing of N. A. C. A. 23012 section consistently exhibited the poorest recovery characteristics; the wing of the N. A. C. A. 0009 section gave the most outward sideslip; and the wing of N. A. C. A. 6718 section gave inward sideslip. The general effect of flaps was adverse, recovery being retarded. For the low value of the relative-density parameter, however, their effect was somewhat favorable when the elevators were neutral or down. This result is in agreement with previous spin-tunnel results, which indicated that deflecting the flaps tends to have a favorable effect upon a steep spin but an adverse effect upon a flat spin for the condition of elevators neutral or down. The Army standard wing, which has Army tips and is tapered in both plan form and thickness, indicated more satisfactory recovery characteristics than the basic rectangular wing.

The effect of control setting on the characteristics is given by a comparison of figures 6 to 9. Spins with elevators neutral and rudder with the spin were very similar to the corresponding spins with elevators down. Corresponding recoveries by full rudder reversal were also similar for the two elevator positions, although several wings gave slower recoveries with elevators down than with elevators neutral. With the elevators down, for the low value of the relative-density parameter, wings 3, 4, and 5 would not spin although spins were obtained when the elevators were neutral. The most rapid recoveries were obtained from spins with elevators full up, by simultaneous reversal of both controls, or by rudder reversal alone. Wings that had given unsatisfactory recoveries with elevators down gave faster recoveries by reversal of rudder alone, with elevators held full up, than by simultaneous reversal of both controls, thus indicating the importance of full rudder reversal before moving the stick forward. The results indicated that complete rudder reversal followed by moving the stick forward would have the advantage of rudder reversal with a minimum of shielding in addition to possible favorable action of the elevators in providing a pitching moment tending to aid recovery. In general, elevator setting had little effect upon the angle of attack of the steady spin, although the elevator-up spins were slightly steeper, had higher rates of descent, less outward sideslip, and lower values of $\Omega b/2V$ than the elevator-down spins.

Spins with both controls neutral were hard to obtain as the model would not spin with this control setting for many conditions. (See fig. 9.) Spins obtained were steeper with higher rates of descent than the corresponding spins with rudder full with (and elevators neutral). Recovery by simultaneously moving the rudder to full against and the elevators to full down was somewhat faster than obtained by reversal of rudder from full with to full against with the elevators neutral.

The results with tail A indicated that, in general, the fastest recoveries were associated with the steepest spins. For any given value of the relative-density parameter, the steepest spins were associated with the highest rates of descent and the lowest values of $\Omega b/2V$, but there was no consistent relationship between the sideslip of the steady spin and the turns required for recovery.

Tests with tail B (figs. 10 to 13).—As previously noted, tail B differs from tail A primarily in that the rudder area was reduced from 5 to 3 percent of the wing area by making the portion of the rudder behind the fuselage fixed fin area. The results of the tests with the reduced rudder area are given in figures 10 to 13, corresponding to figures 6 to 9 for tail A.

A comparison between the two groups of figures shows that tail B gave consistently steeper spins than tail A for all values of the relative-density parameter and elevator settings when the rudder was with the spin, because of the increase in the fixed vertical surface. In some instances, spins could not be obtained with tail B for conditions that gave spins with tail A. For all conditions where tail B gave spins, however, the recoveries were slower than for tail A. The comparison shows the importance of unshielded rudder area for effecting satisfactory recoveries from fully developed spins. With the rudder neutral, the two tails generally gave very similar spins, but tail A gave the more rapid recoveries.

The general nature of the effects of relative density, wing arrangement, and control setting for tail B was very similar to that for tail A. The magnitudes of the effects were much greater with tail B to the extent of being critical as regards recovery characteristics. The beneficial effects of low relative density and the adverse effects of high relative density were very much more apparent.

With tail B, the wing of N. A. C. A. 6718 section tended to give better recovery at a high value of the relative-density parameter than the other two sections. With this tail, in several instances, recovery from the normal spin with elevators up by reversal of both controls appeared to be somewhat more satisfactory than by reversal of rudder alone. This fact would seem to indicate that the pitching moment associated with moving the elevators down in a steep spin might be an aid to a relatively ineffective rudder in effecting recovery. The elevators should not, of course, be moved down before the rudder is reversed.

The critical effects of relative density indicated by this tail arrangement may account for some of the marked differences sometimes reported when a given airplane is spun at different altitudes.

Tests with tail C (figs. 14 to 17).—When tail C (the fin and rudder of tail B atop a shallow fuselage) was installed on the model, the spins were very similar to those with tail A when the rudder was with the spin. The decreased rudder area with the spin apparently tended to balance the effect of the decreased fin area. The lack of rudder control, however, generally led to very much poorer recovery characteristics with tail C. Here, again, on the basis of the slower recoveries obtained from spins with elevators down, it may be inferred that it is desirable to have the reversal of the rudder (from full with the spin) precede the downward deflection of the elevators.

The effects of relative density, wing arrangement, and control setting gave trends similar to those for tails A and B, but the inferiority of tail C was most apparent. With tail C, the poorest from spinning considerations, the model was especially critical to variations in relative density, wing arrangement, or control manipulation. Spins tended to be slightly steeper with tail C than with tail A but could be obtained for several cases where tail A would not give a spin (elevators down). Whereas with the full-length rudder (tail A) it was indicated that full rudder reversal alone was most satisfactory for recovery from elevator-up spins, for tail C, as for tail B, the results indicated that for the shorter rudders, simultaneous reversal of both controls from full with to full against gave faster recoveries than by rudder reversal alone.

A comparison of the three tail arrangements indicates that, as the design of the tail approaches that of tail A with sufficient fin and rudder area below the horizontal surfaces, variations in relative density, wing arrangement, and control manipulation become less important. If the design simulates that of tail C, however, relative density, wing arrangement, and the type of control manipulation in a spin become matters of great importance.

CONCLUSIONS

By analysis of the data presented, the following conclusions may be obtained:

Effects of airplane relative density (wing loading or altitude of the spin):

1. In nearly every case, an increase in the relative density gave flatter spins, higher velocities, lower values of the spin coefficient, and slower recoveries.
2. Except for the wing of N. A. C. A. 6718 section, sideslip generally became more outward as the relative density was decreased.
3. At high values of the relative-density parameter, the effects of wing arrangement, tail arrangement, and control position became very critical.

Effects of wings:

1. *Tip shape.*—Rectangular and faired tips gave the steepest spins, the most outward sideslip, and the most rapid recoveries. The Army tip consistently gave flatter spins and slower recoveries.
2. *Plan form.*—The wing of 5:2 taper generally gave slower recoveries than the rectangular wing.
3. *Section.*—The wing of N. A. C. A. 23012 section consistently exhibited the poorest recovery characteristics. The wing of N. A. C. A. 0009 section gave the most outward sideslip, and the wing of N. A. C. A. 6718 section gave inward sideslip.
4. *Flaps.*—Flaps generally retarded recovery. When, however, the original spin was rather steep, deflection of the flaps tended to aid recovery when elevators were neutral or down.
5. *Army standard wing.*—The Army standard wing gave more satisfactory recovery characteristics than the basic rectangular wing.

Effects of control setting:

1. Recoveries from spins with elevators down were, in general, similar to those with elevators neutral.
2. Holding the elevators up resulted in the steepest spins from which the most rapid recoveries could be obtained. For any tail arrangement, the results indicated that full rudder reversal, followed by moving the elevators full down, would be the most satisfactory manipulation, giving the advantage of pitching moment due to the elevators without shielding of the rudder.

Effects of tail arrangement:

1. The tail with deepened fuselage, raised stabilizer and elevators, and full-length rudder gave the most satisfactory recoveries.
2. The tail with deepened fuselage, raised stabilizer and elevators, and short rudder gave steeper spins but poorer recoveries.
3. The more nearly conventional tail with short rudder atop a shallow fuselage gave the slowest recoveries.
4. The importance of the other variables increased as the effectiveness of the tail unit decreased.

Relationships between spin characteristics:

1. For a given tail arrangement, steepest spins were associated with the fastest recoveries. For a given value of the relative-density parameter, steep spins were associated with low values of the spin coefficient.
2. For a given value of the relative-density parameter, there was no consistent relationship between the sideslip of the steady spin and the turns required for recovery.

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