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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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WIND-TUNNEL INVESTIGATION OF THE SPINNING CHARACTERISTICS OF A MODEL OF A TWIN-TAIL LOW-WING PERSONAL-OWNER-TYPE AIRPLANE WITH LINKED AND UNLINKED RUDDER AND AILERON CONTROLS

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Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

A spin investigation has been conducted in the Langley 20-foot free-spinning tunnel of a model of a twin-tail low-wing personal-owner-type airplane with linked and unlinked rudder and aileron controls. The model was tested for two wing loadings and three mass distributions.

The results obtained when the rudders and ailerons were linked for two-control operation indicated that the model generally would not spin. The spins that were obtained were steep, and the test results indicated that full reversal of the controls from any spinning condition would result in satisfactory recovery.

A study of the individual effects of rudders and ailerons at the various loadings showed that when a spin was obtained the inboard aileron (right aileron in a right spin) when deflected up was largely responsible for maintaining the spin. The results indicated that a reverse differential aileron system having the up aileron movement limited to a very small deflection would be effective in preventing the spin. The outboard rudder (left rudder in a right spin) was the more effective rudder in terminating or maintaining the spin, and differential rudder deflections which maintained the outboard rudder at or near neutral were particularly effective in preventing the attainment of spinning equilibrium.

INTRODUCTION

The Langley Laboratory of the NACA is conducting an investigation to provide data that will be helpful in proportioning the mass and dimensional characteristics of light airplanes to eliminate the spin or to provide good spin-recovery characteristics. An approximate criterion for designing the tail of a light airplane for good spin recovery from fully developed spins has been presented in reference 1. This criterion was based on available test results from the Langley 20-foot free-spinning tunnel of models of approximately 60 military designs considered to have proportions of mass and dimensional characteristics similar to those of light-airplane designs. This work is now being extended to cover spinproofing as well as spin recovery for a range of model configurations and loadings typical of personal-type aircraft. The results presented herein are for a particular model having interconnected aileron and rudder controls and limited elevator deflection.

In addition to determining the effect of simulated two-control operation with the rudders and ailerons linked, the individual effects of the rudders, ailerons, and elevators in producing a spin for the model were also determined in the present investigation. The model was tested for two different wing loadings and for three different mass distributions. In the present study, requirements for spinproofing this particular model were determined and an estimate of the probable recovery characteristics was made from a study of the spin behavior for different control deflections.

The model used was of such size as to be considered a $\frac{1}{11}$-scale model of an airplane of the personal-owner type. The results are given, therefore, in terms of a full-scale airplane on the basis of a $\frac{1}{11}$-scale model.

SYMBOLS

S	wing area, square feet
b	wing span, feet
m	mass of airplane, slugs
$\overline{c}$	mean aerodynamic chord, feet
$x/\overline{c}$	ratio of the distance of center of gravity rearward of leading edge of mean aerodynamic chord to the mean aerodynamic chord
$z/\overline{c}$	ratio of the perpendicular distance between center of gravity and fuselage reference line to the mean aerodynamic chord (positive when center of gravity is below fuselage reference line)
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2

$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
ρ	air density, slugs per cubic foot
μ	airplane relative density $\left(\frac{m}{\rho Sb}\right)$
α	angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, revolutions per second
URVC	unshielded rudder volume coefficient (see reference 1)
TDR	tail damping ratio (see reference 1)
TDPF	tail-damping power factor (see reference 1)

For this model, the helix angle, the angle between the flight path and the vertical, was approximately 7°.

Sideslip at the center of gravity of the model in the spin is considered inward when the inner wing is down by an amount greater than the helix angle. (Angle of sideslip equals the angle between span axis and horizontal minus the helix angle.)

APPARATUS AND METHODS

Model

The $\frac{1}{11}$-scale model used for the tests corresponded to an airplane of the dimensional characteristics presented in table I. A three-view drawing of the model is given in figure 1 and a photograph of the model is presented in figure 2. The model was tested without a propeller.

For the tests, the model was ballasted with lead weights to represent an airplane at an altitude of 5000 feet ($\rho = 0.002049$ slug/cu ft). The normal weight, moments of inertia, and center of gravity of the airplane were selected on the basis of dimensions of an airplane typical of this type.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that for the Langley 15-foot free-spinning tunnel described in reference 2 except that the model launching technique has been changed. With the controls set in the desired position, the model is now launched by hand with rotation into the vertically rising air stream. After the model assumes a fairly constant spin attitude, the spin parameters α, Ω, ϕ, and V are measured and recorded. The model values are converted to full-scale values by methods described in reference 2. For the spins which have a rate of descent in excess of that which can readily be obtained in the tunnel, either the rate of descent is recorded as greater than the velocity at the time the model hits the safety net or the spin is referred to in a footnote on the chart as merely a "steep spin." When the model after being launched with forced rotation into a spin stopped rotating without movement of the controls, the result is recorded as a "no spin" condition. A photograph of the model during a spin in the tunnel is shown in figure 3.

Recoveries from steady spins were not attempted for this model because it appeared that recovery characteristics could be estimated with sufficient accuracy. The turns required for recovery are normally considered from the time the controls are moved until the time the spin rotation ceases.

The term "linked controls" used throughout this paper indicates that the rudders and ailerons were set in such a manner as to simulate an interconnection between them for two-control operation of the airplane. Thus, when rudders were set with the spin (right wheel in a right spin), the ailerons were also with the spin (right aileron up and left aileron down in a right spin). The term "wheel setting" refers to the control wheel of the airplane and indicates the deflection of the ailerons and rudders; "wheel with the spin" indicates that for a right spin the right aileron is up, the left aileron is down, and both rudders are deflected to the right.

PRECISION

The model test results presented are believed to be the true values given by the model within the following limits:

α, degree	±1
ϕ, degree	±1
V, percent	±5
Ω, percent	±2

The preceding limits may have been exceeded for the spins which were difficult to control in the tunnel because of the high rate of descent or oscillatory nature of the spin.

Comparison between model and airplane spin results (references 2 and 3) indicates that tunnel spin results are not always in complete agreement with full-scale spin results. In general, the model spins at a somewhat smaller angle of attack, at a somewhat higher rate of descent, and with 5° to 10° more outward sideslip than would a corresponding airplane. As regards recovery characteristics, reference 3 shows that 80 percent of the model recoveries satisfactorily predicted the corresponding full-scale-airplane recoveries and that 10 percent overestimated and 10 percent underestimated the full-scale-airplane recoveries.

Because of the limits of accuracy within which the model could be ballasted and because of inadvertent damage to the model during the tests, the measured weight and mass distribution of the model varied from the selected values by the following amounts:

Weight, percent	2 low to 2 high
Center-of-gravity location, percent $\bar{c}$	3 forward to 3 rearward of normal
I_X, percent	5 low to 5 high
I_Y, percent	5 low to 5 high
I_Z, percent	4 low to 4 high

The accuracy of measuring the weight and mass distribution is believed to be within the following limits:

Weight, percent	±1
Center-of-gravity position, percent $\bar{c}$	±1
Moments of inertia, percent	±5

The controls were set within an accuracy of $\pm 1^{\circ}$.

Test Conditions

Spin tests were performed for the model conditions listed in table III. The mass characteristics for the model at the various loadings tested are indicated in table II and have been converted to corresponding full-scale values. For the normal loading condition (loading 1), the distribution of weight was such that the moment of inertia about the X-axis I_X was approximately equal to the moment of inertia about the Y-axis I_Y and the value of the inertia yawing-moment parameter $\frac{I_X - I_Y}{mb^2}$ was thus approximately zero. For loading 2, the mass distribution along the fuselage was increased until the inertia yawing-moment parameter equaled -49×10^{-4}; and for loading 3, the mass distribution along the wings was increased until the value of the inertia yawing-moment parameter was 165×10^{-4}. For loading 4, the relative density of the model was approximately doubled by increasing the weight and moments of inertia, keeping the radii of gyration about the center of gravity approximately the same as for loading 1. The mass-distribution parameters for the four loading conditions given in table II are plotted in figure 4. Because of an inadvertent error in model ballasting calculations, loading 2, although a possible light-airplane loading, is not the limit of the full range possible for airplanes that have the weight distributed primarily along the fuselage, whereas loading 3 probably exceeds the range of loadings that might be expected for single-engine light airplanes having the greater part of the weight distributed along the wings.

All tests were conducted with the canopy closed and with a fixed landing gear installed on the model.

In order to simulate two-control operation now found on some light airplanes, the rudder and aileron controls were considered linked for some of the tests. The control deflections are given in terms of a control wheel and are as follows:

Wheel position	Rudder deflection, deg		Aileron deflection, deg	
	Left	Right	Left	Right
Full right wheel	$1\frac{3}{4}$ right	$27\frac{1}{2}$ right	5 down	$51\frac{1}{2}$ up
One-half right wheel	$3\frac{1}{2}$ right	$8\frac{1}{2}$ right	$9\frac{3}{4}$ down	$21\frac{1}{2}$ up
One-third right wheel	3 right	$4\frac{3}{4}$ right	$8\frac{1}{2}$ down	$11\frac{1}{2}$ up
One-fourth right wheel	$2\frac{1}{2}$ right	$3\frac{1}{2}$ right	7 down	8 up

Plots of the control deflections for any wheel position are shown in figure 5.

Normal elevator deflections for the linked-control tests were chosen as 13° up and 12° down. The value of 13° up was chosen as the probable minimum value that would permit the corresponding airplane to be landed satisfactorily. Elevator deflections of 20° and 30° up were also tested, however, to determine the effect of increased up elevator deflections. In addition, tests were made with the controls unlinked to determine the independent effects of the rudders and ailerons.

RESULTS AND DISCUSSION

The results of the spin tests of the model with linked-control settings are presented in charts 1 to 4 and with unlinked-control settings in charts 5 to 8. The normal-spinning-control configuration for a two-control airplane having linked rudders and ailerons is different from that for an airplane utilizing a three-control system: For the two-control airplane, ailerons and rudders are both moved with the spin for normal entry into a spin; whereas, for the conventional airplane, the ailerons would be placed at neutral and only the rudders would be moved with the spin. The model data given in the charts are presented in terms of the full-scale values for a corresponding airplane at a test altitude of 5000 feet.

Preliminary tests of the model showed that steady-spin data for left and right spins differed very little. Results are, therefore, arbitrarily presented in terms of equivalent right spins, that is, for the airplane turning to the pilot's right.

Linked Controls

Normal loading (loading 1).- The test results obtained with the model in the normal-loading condition with linked rudders and ailerons simulated are presented in chart 1. The model condition is represented by loading 1 in table II and point 1 in figure 4. For the normal-control configuration for spinning (wheel full with the spin and elevator at its normal full-up deflection of 13°), the model did not reach a spin equilibrium but descended at a steep attitude in a wide radius in the tunnel and at a vertical velocity exceeding the maximum tunnel velocity. The motion appeared to be a steep spiral rather than a spin. Film-strip photographs of the typical model motion at this control configuration are shown in figure 6. When the wheel was set at only one-half with the spin, however, definite spins were obtainable at up elevator deflections of 8° and higher. Photographs of the model during a typical spin with the wheel set at this position and with the elevator set at its normal full-up deflection (13°) are shown in figure 7. No recoveries were attempted from these spins; but when the model was launched into the tunnel with the wheel set at neutral or against the spin at the various up elevator deflections for which spins were obtained, the original rotation imparted to the model on launching damped out rapidly; recoveries from any spins were thus indicated to be satisfactory when the wheel was moved to neutral or against the spin.

Neutral and down deflections of the elevator were favorable in preventing the spin; whereas up elevator deflections were conducive to the attainment of spinning equilibrium. From the foregoing results it appears that the fastest recoveries from any spin obtainable would have been effected by reversal of the wheel followed by a downward movement of the elevator.

Mass changes (loadings 2 and 3).– Test results obtained with the mass distribution increased along the fuselage are shown in chart 2, and results obtained with the mass distribution increased along the wings are shown in chart 3. These model conditions are represented, respectively, by loadings 2 and 3 in table II and points 2 and 3 in figure 4. More spins were obtained for loading 2, in which the elevator was set between neutral and full up for wheel settings with the spin, than were obtained for the normal-loading condition. Loading 3 gave results very similar to those for the normal loading.

Increased relative density (loading 4).– Chart 4 shows the results obtained with the weight of the model approximately doubled and with the radii of gyration about the center of gravity (and the mass-distribution parameters) kept approximately the same as for the normal loading (loading 4 in table II and point 4 in fig. 4). The test results obtained at this loading differed from results obtained at the normal loading in that definite spins were now obtained when the wheel was full with the spin and the elevator deflected up normally (13°). Test results obtained at other control configurations were generally the same as those obtained at the normal loading although, when the wheel was full with the spin and the elevator was either neutral or down, a spiral motion was obtained where definite "no spin" conditions had previously been obtained. At this loading, it was possible to obtain a spin with wheel-neutral control settings by deflecting the elevator to 30° up.

Unlinked Controls

In order to establish the individual effects of the ailerons and the rudders in the spin, tests were made with the ailerons deflected when the rudders were neutral and with the rudders deflected when the ailerons were neutral. The results of these tests are presented in charts 5 to 7.

Effect of ailerons.– With the rudders maintained at neutral, the aileron deflections were varied from full against to full with the spin for loadings 1 and 2. The elevator was kept at normal full up (13°) for these tests, and the results are presented in chart 5. Analysis of the results presented indicates that the greatest tendency to spin would occur for the model when the ailerons were placed at one-half or near one-half with the spin.

Chart 6 shows the results obtained at loadings 1 to 4 when the right and left ailerons were deflected individually and the rudders were kept at neutral.

The results indicated that: When the inboard aileron was maintained at neutral, no spin was obtained regardless of the outboard aileron deflection; whereas, when the inboard aileron was deflected from approximately three-tenths to six-tenths of its maximum full-up deflection, a spin was obtained regardless of the position of the outboard aileron.

It thus appears from the results that in order to spinproof an airplane proportioned similarly to the model tested, limiting the up aileron to about 5° would be desirable. The normal differential aileron movements employed for the linked-control tests appear ineffective in preventing the spin.

Effect of rudders.- With the ailerons maintained at neutral, the rudder deflections for loadings 2, 3, and 4 were varied from neutral to as much as 20° with the spin for the outboard rudder and to as much as 45° with the spin for the inboard rudder. The elevator was kept at its normal full-up deflection (13°) for these tests, and the results are presented in chart 7. The results show that if the outboard rudder was at or near neutral, no spin could be obtained regardless of the position of the inboard rudder. If the outboard rudder was set with the spin, however, the results indicate that spins could be obtained even if the inboard rudder was at neutral. The amount the outboard rudder had to be set with the spin in order to obtain a spinning condition varied somewhat with loading. The results show that the outboard rudder was the more effective rudder during the spin and that differential rudder deflection in which the outboard rudder is maintained at or near neutral is effective in preventing the attainment of spinning equilibrium when the ailerons are neutral.

Tests in which the model was launched with the rudders set against the spin are presented in chart 8 for loadings 3 and 4. The results indicate that for loading 4 (increased relative density) the model would not spin when both rudders were 20° against the spin even though the aileron deflection was such as to be very conducive in causing the model to spin. The model ceased spinning quickly after being launched into the tunnel, thereby indicating that recovery by movement of the rudders from with the spin to against the spin would have been rapid. When, however, the mass was distributed heavily along the wings (loading 3), the results indicate that rudder reversal alone would not effect recovery. Inasmuch as references 1 and 4 indicate that rudder effectiveness decreases and elevator effectiveness increases as the mass distribution of airplanes is increased along the wings, this result appears reasonable; thus, in order to obtain satisfactory recovery at loading 3, rudder reversal would have to be followed by a downward movement of the elevator. For loading 4, on the other hand, the results indicate that even though the relative density was comparatively high ($\mu = 10$ approx.) the rudders were effective in terminating the spin for this mass distribution $\left(\frac{I_X - I_Y}{mb^2} = -18 \times 10^{-4}\right)$. On the basis of the results obtained at loading 4 and on the basis of reference 5, which indicates that decreased relative density improves recovery, it can be concluded that rudder action alone would have been effective in terminating spins obtained for loadings 1 and 2.

Spinproofing

The data presented in the charts indicate that at the lower of the two wing loadings tested (approx. 10 lb/sq ft) limiting the up elevator deflection to 13° (assumed to be the minimum up elevator deflection required to land the airplane satisfactorily), limiting the up aileron movement to about 5°, and limiting the outboard rudder (left rudder in a right spin) so that it can not be set with the spin would prevent the attainment of spinning equilibrium. In order to maintain satisfactory rolling characteristics in normal flight by utilizing only a 5° maximum up aileron deflection, it will be necessary to have a reverse differential aileron movement (that is, greater down aileron than up aileron deflection). Computations made by the methods outlined in reference 6 show that if the ailerons are sealed a down aileron deflection of 16° and an up aileron deflection of 5° will give a maximum value of $\frac{pb}{2V}$ (helix angle generated by the wing tip in a roll) equivalent to 0.07, the minimum permissible value specified in reference 6. The adverse yawing moments contributed by the ailerons utilizing a 5° up and 16° down deflection were computed by methods given in references 7 and 8. Model force-test data were available for computing the yawing moments contributed by the rudder for small rudder deflections. Computations made by approximate methods to determine the yawing moments contributed by the rudders at large deflections (that is, deflecting one rudder to 45° and maintaining the other rudder at neutral) showed that the adverse yawing moments contributed by a full aileron deflection could be overcome by the rudder. The effects of slipstream rotation were neglected for these calculations. Practical considerations probably prohibit the use of a rudder deflection, however, as high as 45°; and in order to maintain satisfactory flight characteristics, it thus appears necessary to increase the size of the vertical tails so that a smaller rudder deflection could be used. On the basis of previous experience in the spin tunnel, it appears that if the size of the fin and rudder are increased in a manner to maintain the same proportions as the existing fin and rudder the airplane would probably still be spinproof.

The test data obtained during the investigation were not extensive enough to permit determination of the control limitations necessary for spinproofing at the higher wing loading.

CONCLUSIONS

The results of spin tests of a $\frac{1}{11}$-scale model of a twin-tail low-wing personal-owner-type airplane with controls linked and unlinked indicated the following spin and recovery characteristics at a test altitude of 5000 feet:

For linked rudder and aileron controls:

1. For the normal loading condition, spins were obtainable only when the wheel was placed approximately one-half with the spin and the elevator was deflected upward to at least 8°. Setting the wheel farther with the spin lead to a motion that appeared to be a spiral, and setting the wheel laterally to neutral prevented the spin. Moving the elevator down was favorable in preventing the spin. Recoveries obtained by fully reversing the wheel followed by moving the elevator down would undoubtedly have been rapid from any spin.

2. With the mass increased along the fuselage, more spins were obtained with the elevator between neutral and full up for wheel settings with the spin than were obtained for the normal loading condition. With the mass increased along the wings, the results were very similar to those obtained for the normal loading.

3. Approximately doubling the airplane's relative density led to definite spins when the wheel was set full with the spin and the elevator was set to its normal full-up deflection (normal spinning control configuration), but for other wheel and elevator settings little effect was noted.

For unlinked controls:

4. For all loadings ailerons set against the spin tended to prevent the spin; whereas ailerons set with the spin were conducive to the attainment of spinning equilibrium. Deflecting the inboard aileron up was particularly effective in maintaining the spin, especially when it was deflected from approximately three-tenths to six-tenths of its maximum full-up deflection.

5. The outboard rudder was effective in terminating or maintaining the spin when the ailerons were neutral. For loadings with mass extended along the wings, rudder reversal would have to be followed by elevator reversal in order to effect recovery from the aileron-with spins. With the ailerons neutral, differential rudder deflections which maintained the outboard rudder at or near neutral were particularly effective in preventing the attainment of spinning equilibrium.

6. When the corresponding full-scale wing loading of the model was 10 pounds per square foot, it was indicated that spinproofing could be obtained by limiting the aileron movement to 5° up, by limiting the outboard rudder movement so that it could not be deflected with the spin, and by limiting the up elevator deflection to 13°. With the controls limited in this manner, an inboard rudder deflection of 45° would be required to provide satisfactory flight characteristics. Inasmuch as a rudder

deflection of this amount is probably impractical, it would appear desirable to increase uniformily the size of the vertical tails so that a smaller rudder deflection would be required.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., November 17, 1948

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF TWIN-TAIL LOW-WING PERSONAL-OWNER-TYPE AIRPLANE

Over-all length, ft	20.08
Wing:	
Span, ft	30.00
Area, sq ft	142.60
Airfoil section (root and tip)	NACA 43013
Incidence (root and tip), deg	2.5
Aspect ratio	6.31
Dihedral, deg	7.0
Sweepback, deg	0
Mean aerodynamic chord, in.	57.10
Leading edge of mean aerodynamic chord aft leading edge of wing, in.	0.87
Taper ratio	1.0
Ailerons:	
Total area, sq ft	16.80
Chord (mean), in.	11.38
Span, in.	113.63
Horizontal tail surfaces:	
Total area, sq ft	19.60
Elevator area, sq ft	9.40
Aspect ratio	3.39
Incidence, deg	0.5
Distance from center of gravity to elevator hinge line, ft	13.25
Twin vertical tail surfaces:	
Total area, sq ft	9.30
Total rudder area, sq ft	6.00
Aspect ratio	2.27
Distance from center of gravity to rudder hinge line, ft	13.25
Tail-damping power factor, TDPF	698×10^{-6}
Unshielded rudder volume coefficient, URVC	0.0240
Tail damping ratio, TDR	0.0291

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TABLE II.– MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADINGS TESTED ON THE MODEL

[Model values converted to corresponding full-scale values]

Loading	Loading condition	Weight (lb)	Wing loading (lb/sq ft)	Relative density		Center of gravity	
				Sea level	5000 feet	$x/\bar{c}$	$z/\bar{c}$
1	Normal	1424	9.99	4.35	5.04	0.182	0.088
2	Mass extended along fuselage	1491	10.46	4.55	5.29	.173	.088
3	Mass extended along wings	1499	10.51	4.57	5.32	.199	.101
4	Relative density approximately doubled from normal loading	2929	20.54	8.93	10.39	.187	.025

Loading	Moments of inertia (slug-ft^2)			Inertia parameters		
	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
1	701	712	1347	-3×10^{-4}	-160×10^{-4}	163×10^{-4}
2	731	921	1583	–49	–154	203
3	1481	790	2127	165	–319	154
4	1289	1440	2588	–18	–140	158

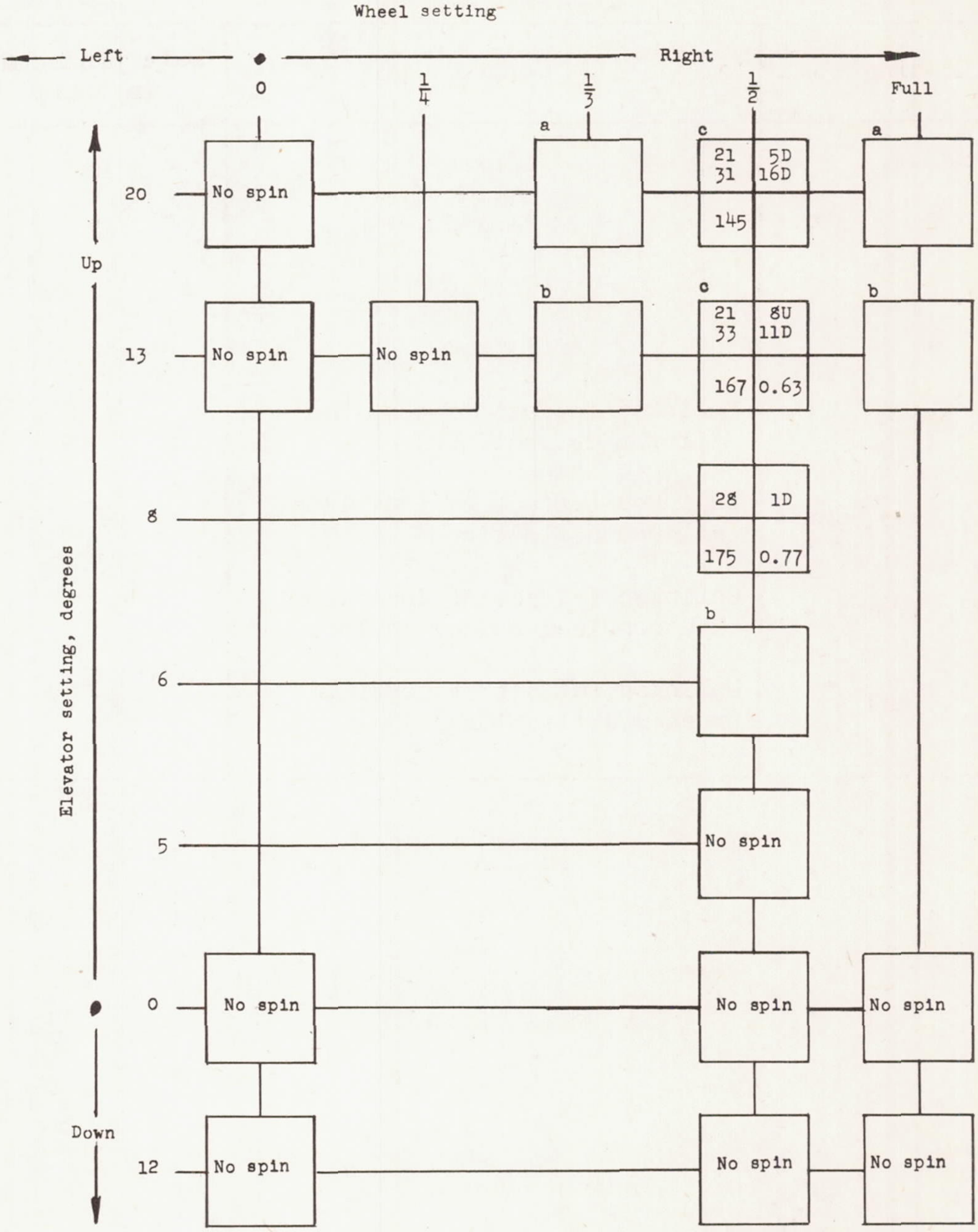
TABLE III.– MODEL TEST CONDITIONS

[Erect spins to pilot's right]

Loading	Controls	Data presented in chart
1	Linked	1
2	Linked	2
3	Linked	3
4	Linked	4
1 and 2	Unlinked (effect of combined aileron deflections)	5
1, 2, 3, and 4	Unlinked (effect of individual aileron deflections)	6
2, 3, and 4	Unlinked (effect of individual and combined rudder deflections)	7
3 and 4	Unlinked (effect of combined rudder deflections)	8

CHART 1.– SPIN CHARACTERISTICS OF MODEL FOR NORMAL LOADING (LINKED RUDDER AND AILERON CONTROLS)

$\left[\frac{I_X - I_Y}{mb^2} = -3 \times 10^{-4};\ \mu = 5.04\right.$ (loading 1 in table II and point 1 in fig. 4); right erect spins$\left.\right]$



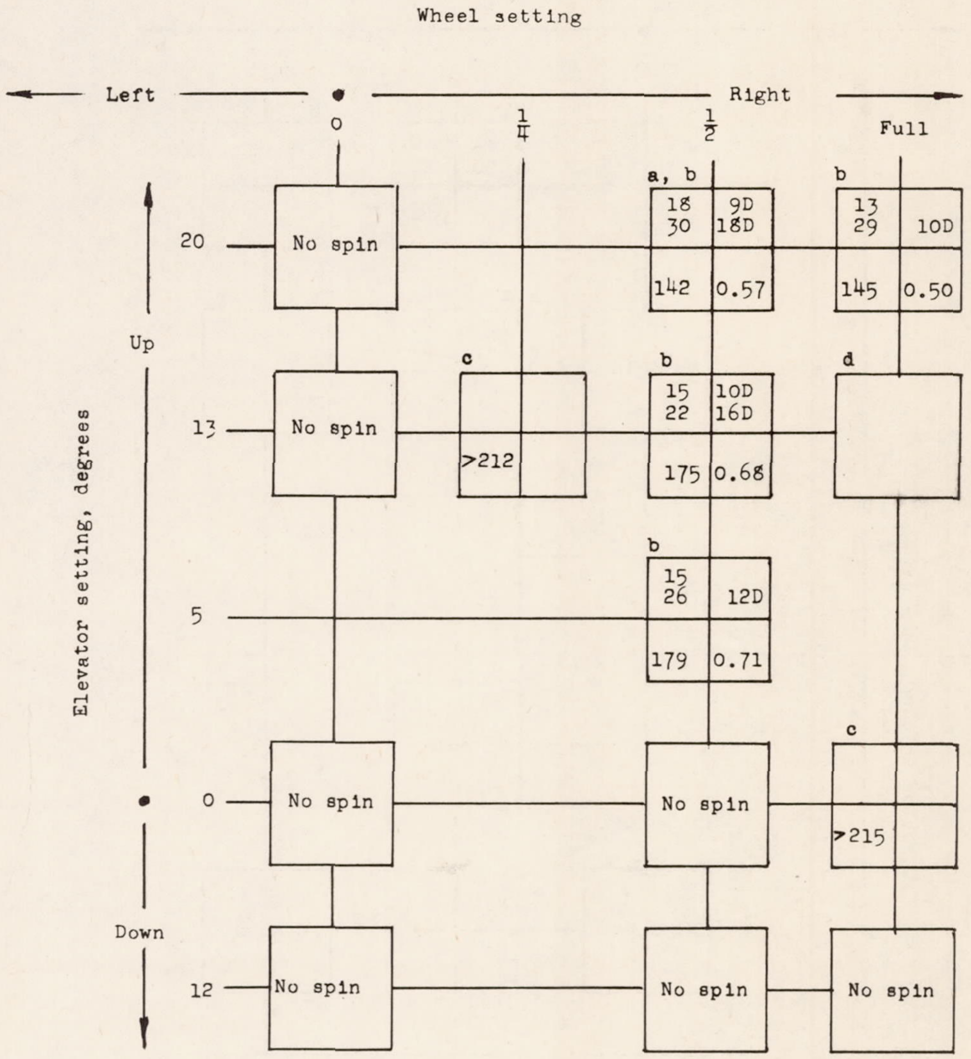
[a] Steep spin, vertical velocity too high to permit obtaining test data.
[b] Steep spiral.
[c] Oscillatory spin, range of values or average value given.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)

CHART 2.- SPIN CHARACTERISTICS OF MODEL WITH MASS DISTRIBUTION INCREASED ALONG THE FUSELAGE (LINKED RUDDER AND AILERON CONTROLS)

$\left[\frac{I_X - I_Y}{mb^2} = -49 \times 10^{-4}\right.$; $\mu = 5.29$ (loading 2 in table II and point 2 in fig. 4); right erect spins$\left.\right]$



Elevator setting, degrees	0	$\frac{1}{4}$	$\frac{1}{2}$	Full
Up 20	No spin		[a, b] 18 30; 9D 18D; 142; 0.57	[b] 13 29; 10D; 145; 0.50
13	No spin	[c] >212	[b] 15 22; 10D 16D; 175; 0.68	[d]
5			[b] 15 26; 12D; 179; 0.71	
0	No spin		No spin	[c] >215
Down 12	No spin		No spin	No spin

[a] Spin has a whipping motion.

[b] Oscillatory spin, range of values or average value given.

[c] Steep spin, velocity too high to permit obtaining test data.

[d] Steep spiral.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)

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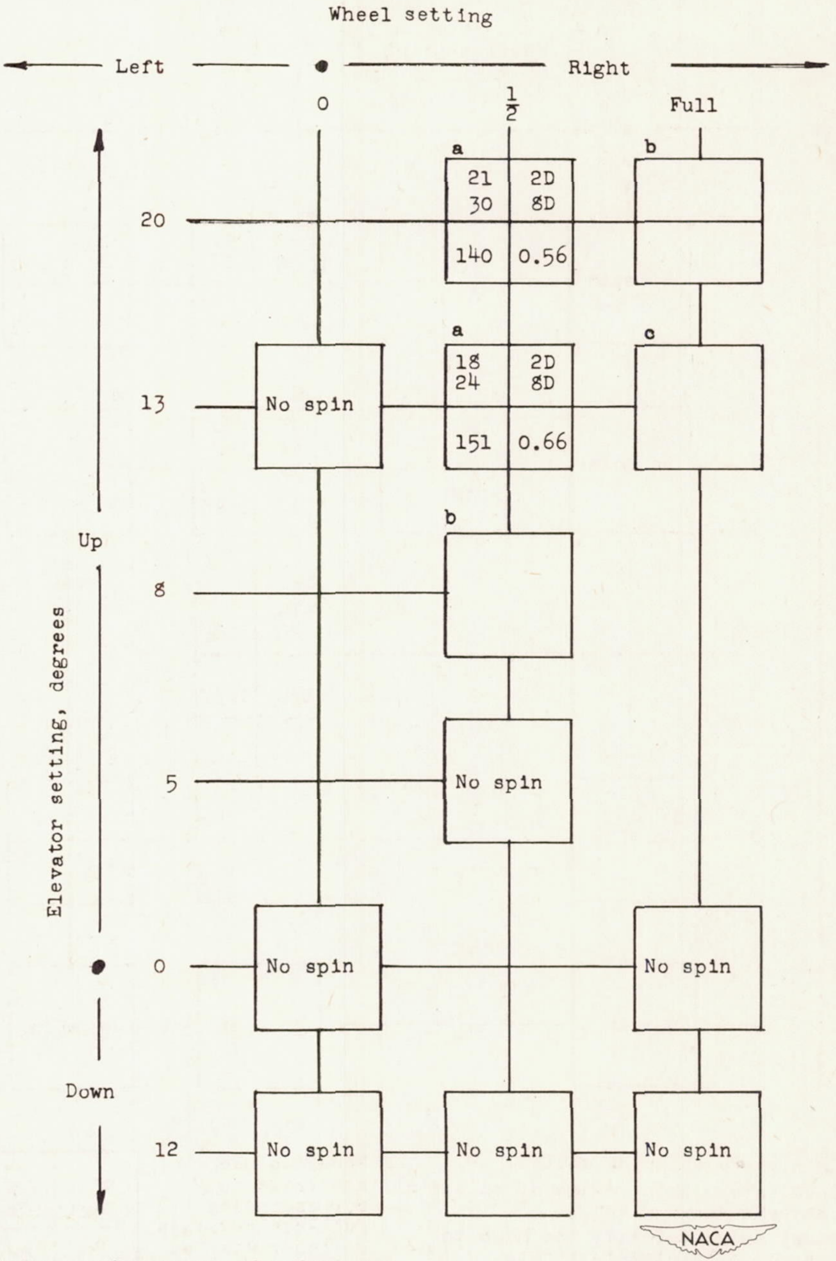
CHART 3.– SPIN CHARACTERISTICS OF MODEL WITH MASS DISTRIBUTION INCREASED ALONG THE WINGS (LINKED RUDDER AND AILERON CONTROLS)

[$\frac{I_X - I_Y}{mb^2} = 165 \times 10^{-4}$; $\mu = 5.32$ (loading 3 in table II and point 3 in fig. 4); right erect spins]



Elevator setting, degrees	0	$\frac{1}{2}$	Full
20 (Up)		[a] 21 2D 30 8D 140 0.56	[b]
13 (Up)	No spin	[a] 18 2D 24 8D 151 0.66	[c]
8 (Up)		[b]	
5 (Up)		No spin	
0	No spin		No spin
12 (Down)	No spin	No spin	No spin

[a] Oscillatory spin, range of values or average value given.

[b] Steep spin, vertical velocity too high to permit obtaining test data.

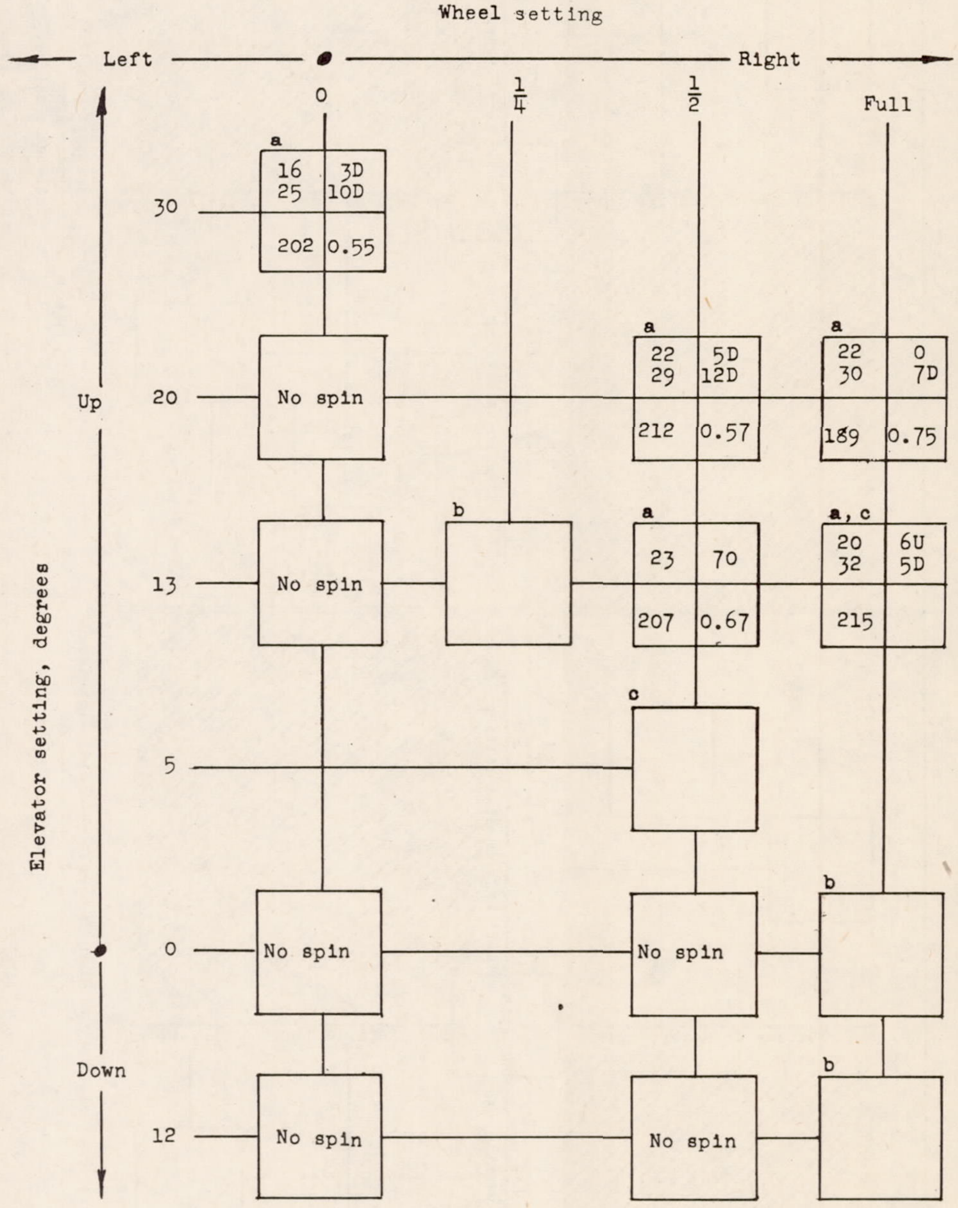
[c] Steep spiral.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)

CHART 4.– SPIN CHARACTERISTICS OF MODEL WITH INCREASED RELATIVE DENSITY
(LINKED RUDDER AND AILERON CONTROLS)

$\left[\frac{I_X - I_Y}{mb^2} = -18 \times 10^{-4};\ \mu = 10.39\right.$ (loading 4 in table II and point 4 in fig. 4); right erect spins$\left.\right]$



[a]Oscillatory spin, range of values or average value given.
[b]Steep spiral.
[c]Wandering spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

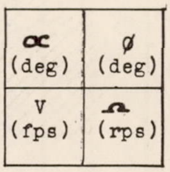
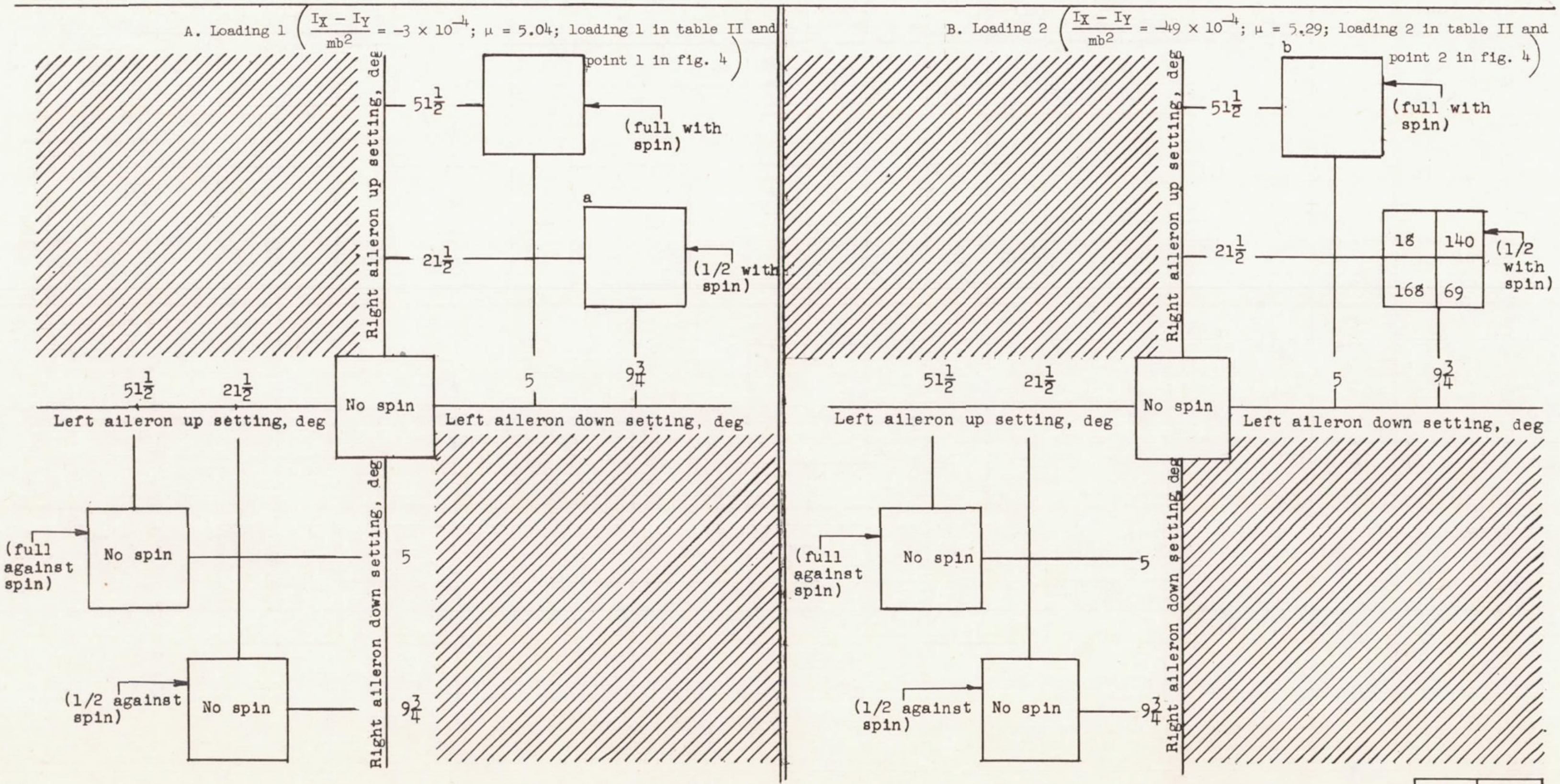


CHART 5.- EFFECT OF COMBINED AILERON DEFLECTIONS ON THE SPIN CHARACTERISTICS OF MODEL (RUDDERS AND AILERONS UNLINKED)

[Right erect spins; elevator set to 13° up, rudders set to neutral, ailerons set as indicated]



A. Loading 1 ($\frac{I_X - I_Y}{mb^2} = -3 \times 10^{-4}$; $\mu = 5.04$; loading 1 in table II and point 1 in fig. 4)

B. Loading 2 ($\frac{I_X - I_Y}{mb^2} = -49 \times 10^{-4}$; $\mu = 5.29$; loading 2 in table II and point 2 in fig. 4)

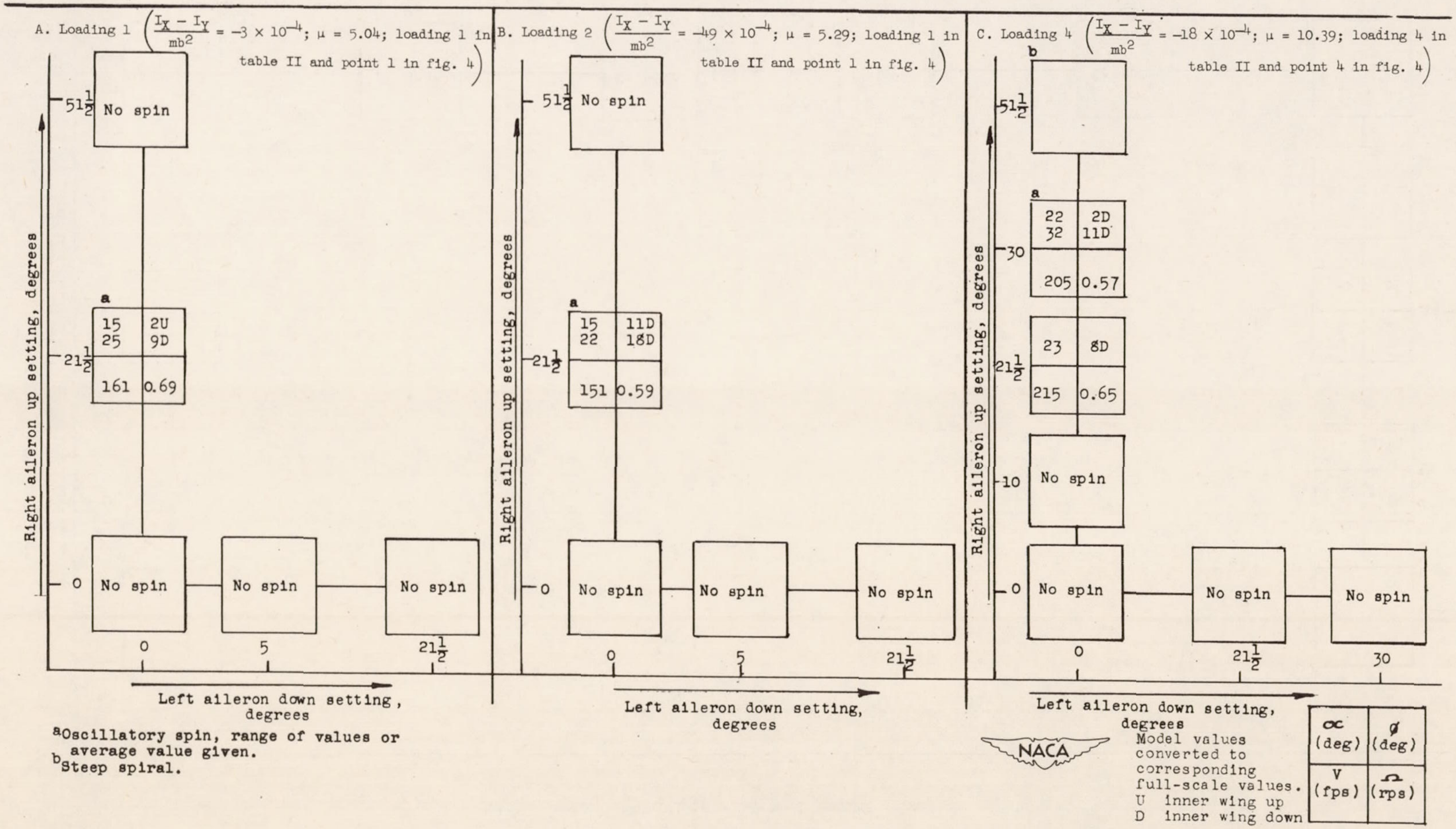
[a]Steep spin vertical velocity too high to permit obtaining test data.
[b]Steep spiral.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)

CHART 6.– EFFECT OF INDIVIDUAL AILERON DEFLECTIONS ON THE SPIN CHARACTERISTICS OF MODEL (RUDDERS AND AILERONS UNLINKED)

[Right erect spins; elevator set to 13° up, rudders set to neutral, ailerons set as indicated]



[a] Oscillatory spin, range of values or average value given.

[b] Steep spiral.

CHART 6.– EFFECT OF INDIVIDUAL AILERON DEFLECTIONS – Concluded

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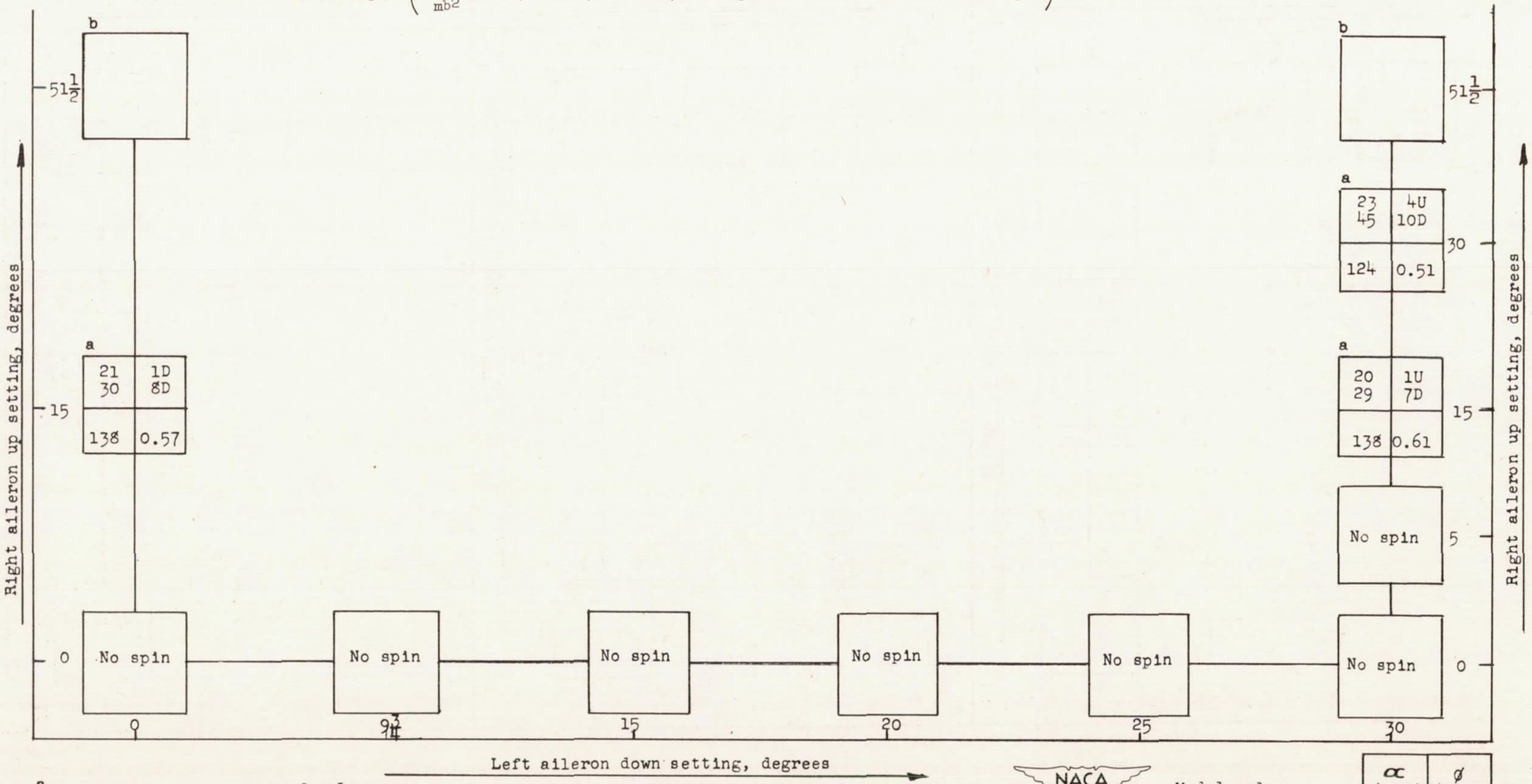
D. Loading 3 $\left(\frac{I_X - I_Y}{mb^2} = 165 \times 10^{-4};\ \mu = 5.32;\right.$ loading 3 in table II and point 3 in fig. 4$\left.\right)$



[a] Oscillatory spin, range of values or average value given.

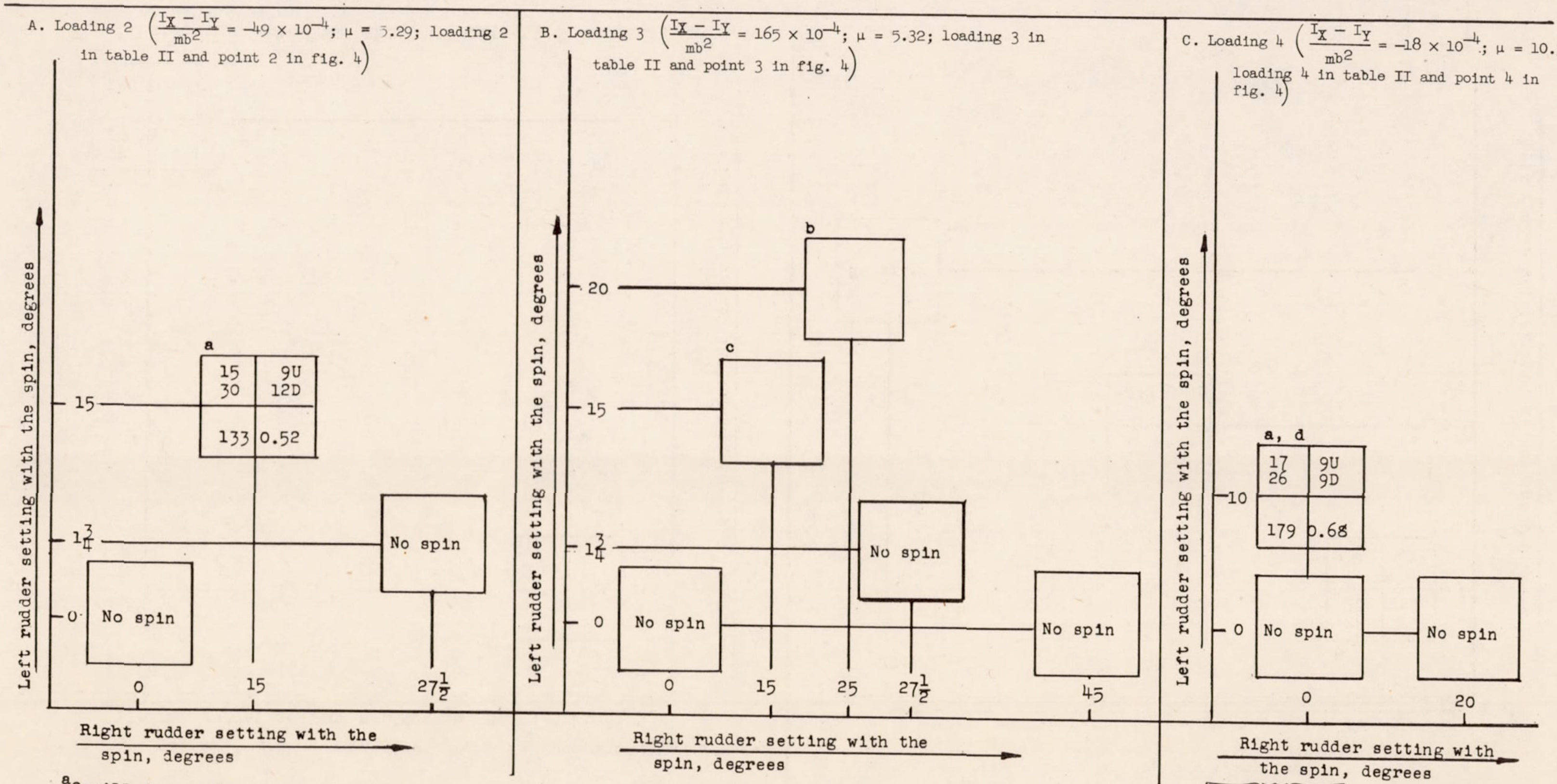
[b] Steep spiral.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)

CHART 7.– EFFECT OF INDIVIDUAL AND COMBINED RUDDER DEFLECTIONS ON THE SPIN CHARACTERISTICS OF MODEL (RUDDERS AND AILERONS UNLINKED)

[Right erect spins; elevator set to 13° up, ailerons neutral, rudders set as indicated]



A. Loading 2 $\left(\frac{I_X - I_Y}{mb^2} = -49 \times 10^{-4};\ \mu = 5.29\right.$; loading 2 in table II and point 2 in fig. 4$\left.\right)$

B. Loading 3 $\left(\frac{I_X - I_Y}{mb^2} = 165 \times 10^{-4};\ \mu = 5.32\right.$; loading 3 in table II and point 3 in fig. 4$\left.\right)$

C. Loading 4 $\left(\frac{I_X - I_Y}{mb^2} = -18 \times 10^{-4};\ \mu = 10.39\right.$; loading 4 in table II and point 4 in fig. 4$\left.\right)$

[a] Oscillatory spin, range of values or average value given.
[b] Two conditions possible
  1. Steep spin, vertical velocity too high to permit obtaining data.
  2. No spin.
[c] Steep spiral.
[d] Wandering spin.

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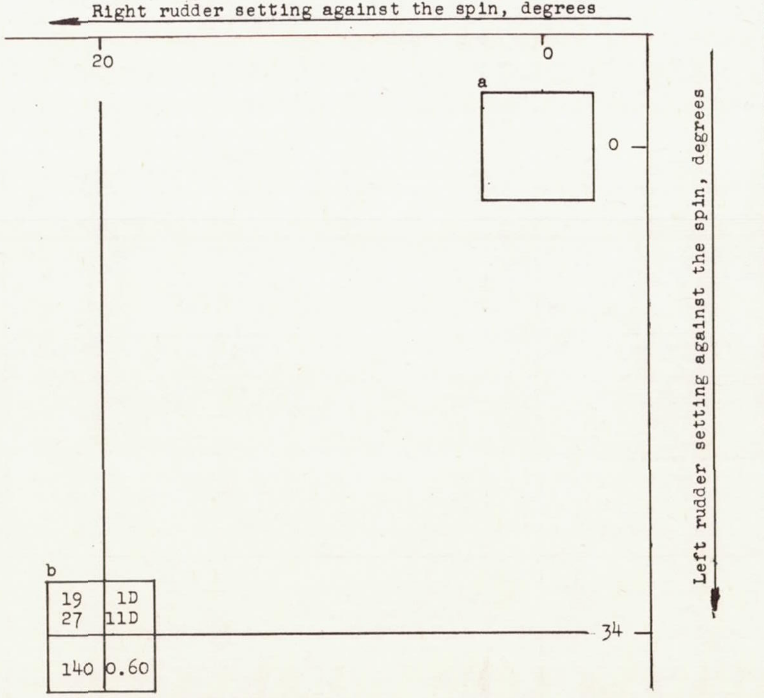
Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)

CHART 8.– EFFECT OF COMBINED RUDDER DEFLECTIONS ON THE SPIN CHARACTERISTICS OF MODEL (RUDDERS AND AILERONS UNLINKED)

[Right erect spins; elevator set to 13° up, rudders and ailerons set as indicated]

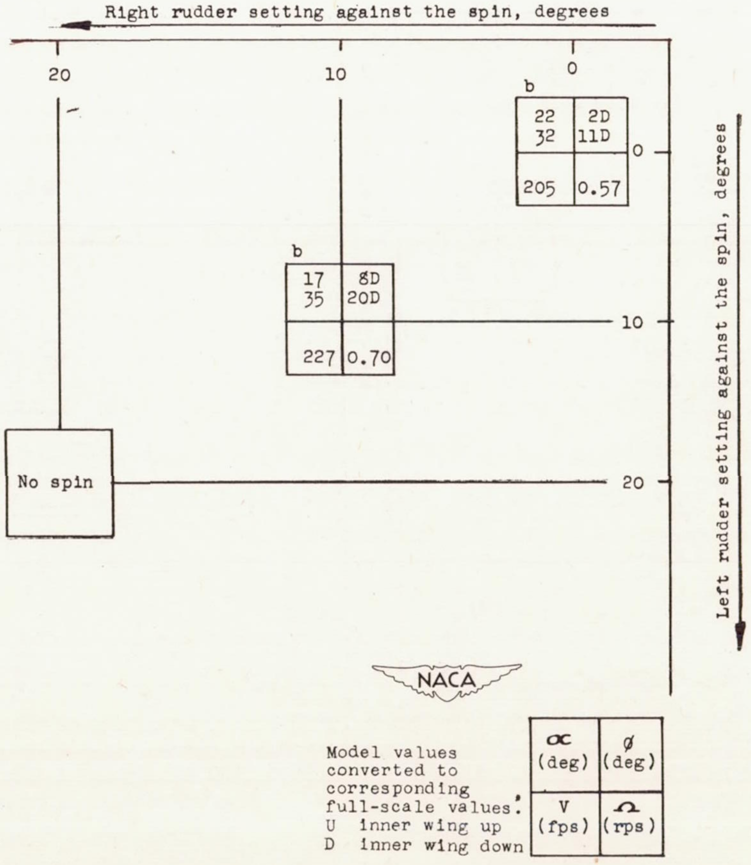
A. Loading 3 $\left(\frac{I_X - I_Y}{mb^2} = 165 \times 10^{-4};\ \mu = 5.32\right.$; loading 3 in table II and point 3 in fig. 4 ; ailerons $\frac{1}{2}$ with the spin; right aileron $21\frac{1}{2}^{\circ}$ up, left aileron $9\frac{3}{4}^{\circ}$ down



[a] Oscillatory spin, too difficult to control in tunnel to permit obtaining data.

[b] Oscillatory spin, range of values or average value given.

B. Loading 4 $\left(\frac{I_X - I_Y}{mb^2} = -18 \times 10^{-4};\ \mu = 10.39\right.$; loading 4 in table II and point 4 in fig. 4); right aileron 30° up, left aileron neutral



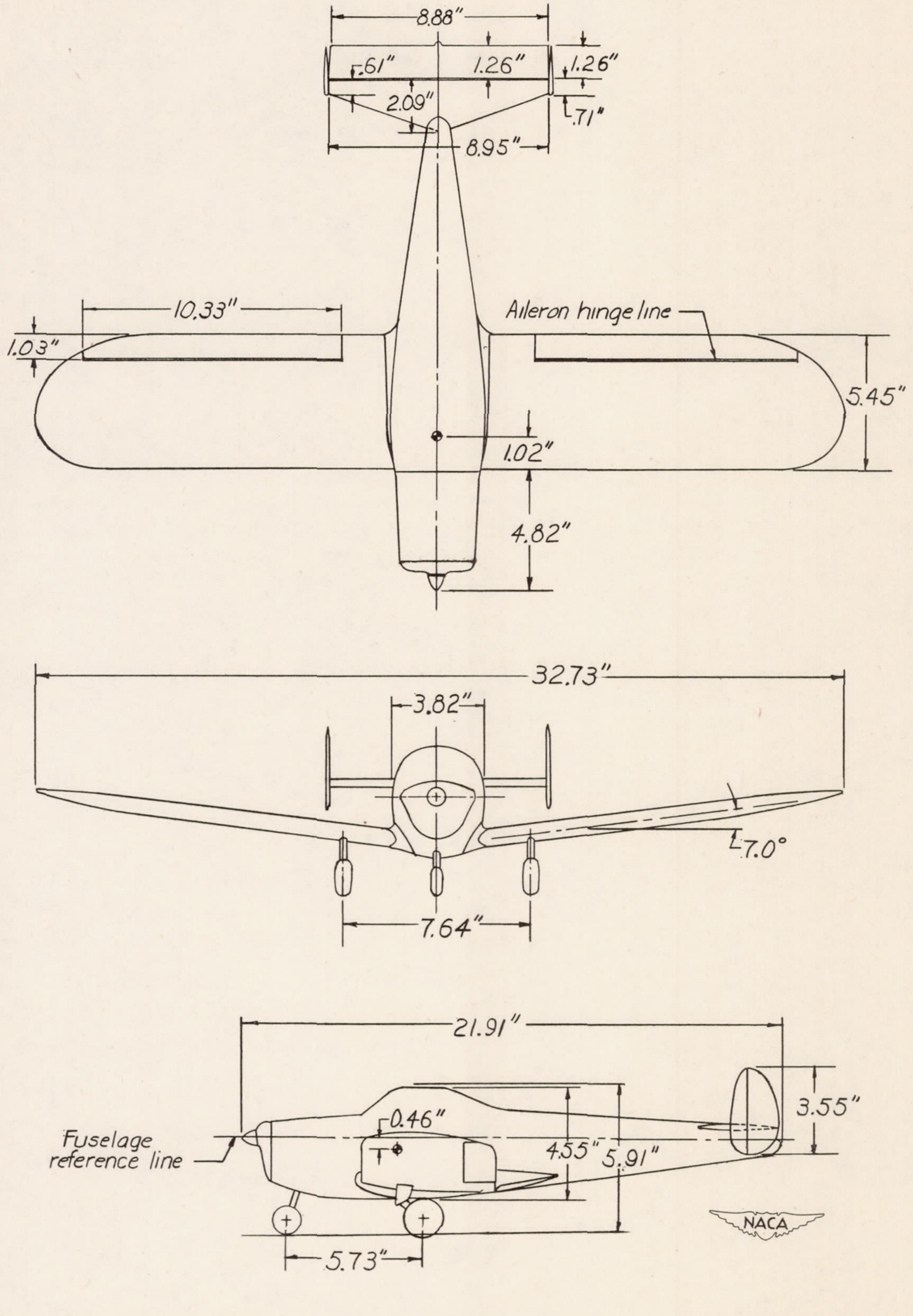


Figure 1.- Drawing of the $\frac{1}{11}$-scale model of the twin-tail low-wing personal-owner-type airplane as tested in the Langley 20-foot free-spinning tunnel. Center of gravity indicated for normal loading.

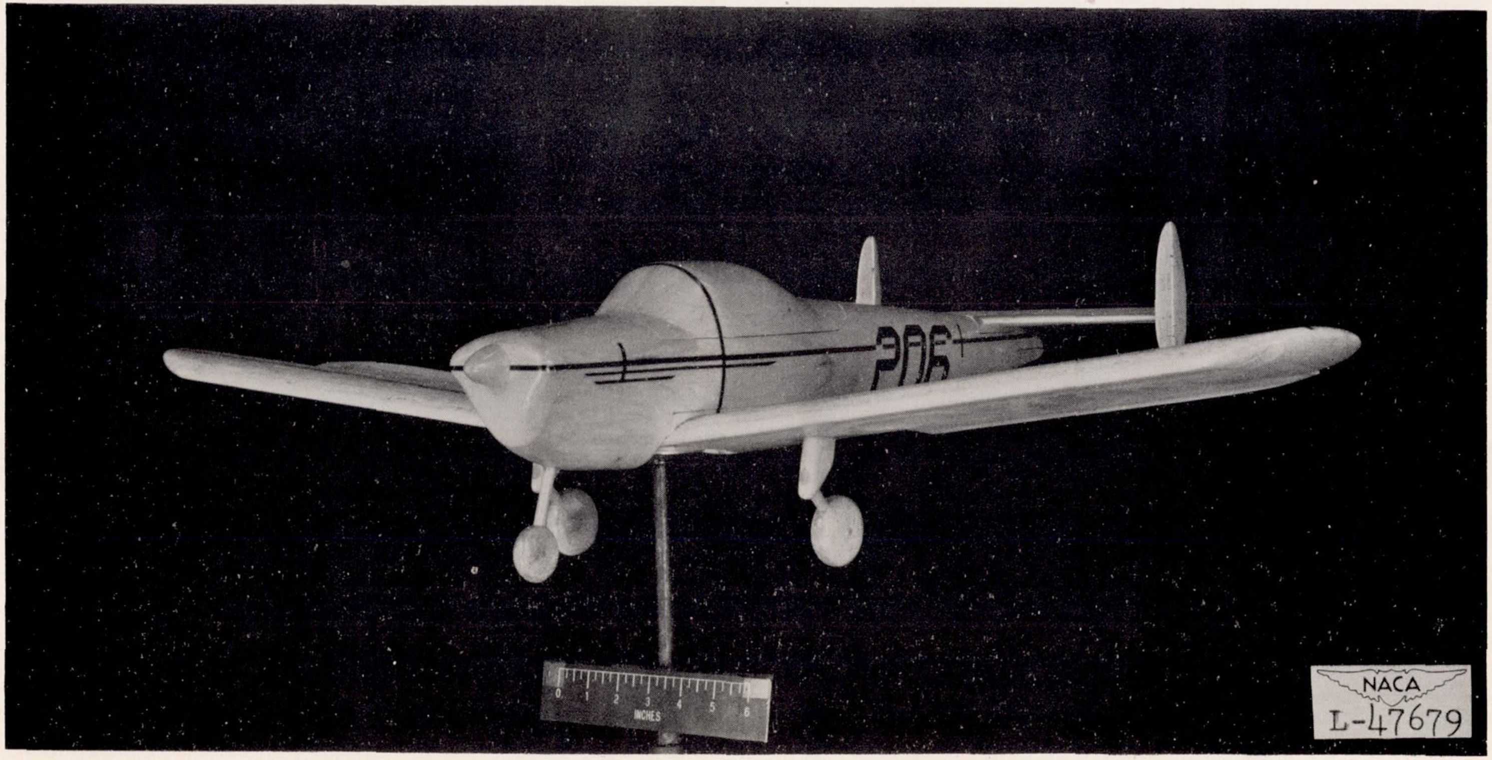


Figure 2.- Photograph of the model as tested in the Langley 20-foot free-spinning tunnel.

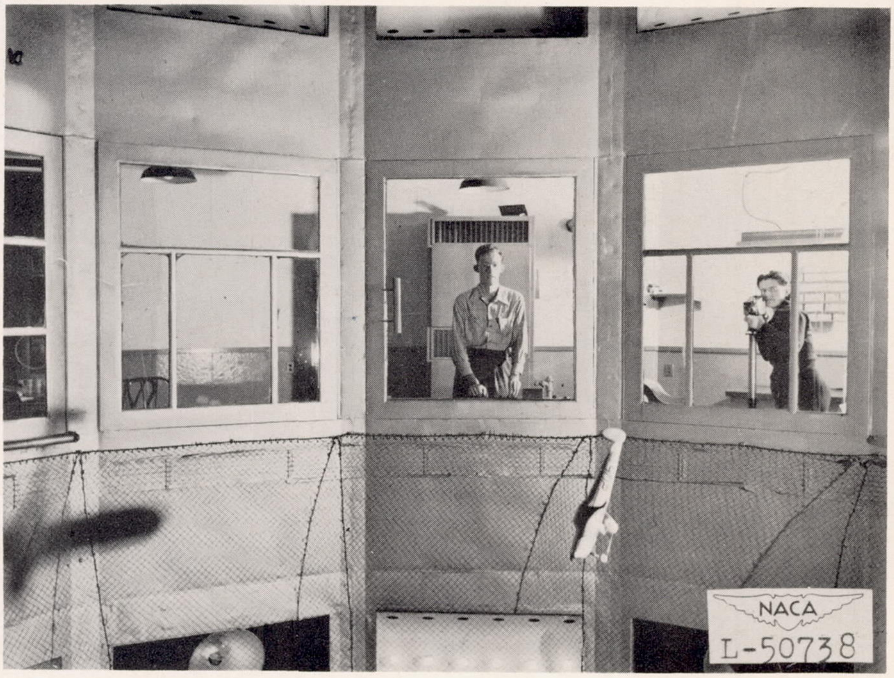


Figure 3.- Photograph of the model spinning in the Langley 20-foot free-spinning tunnel.

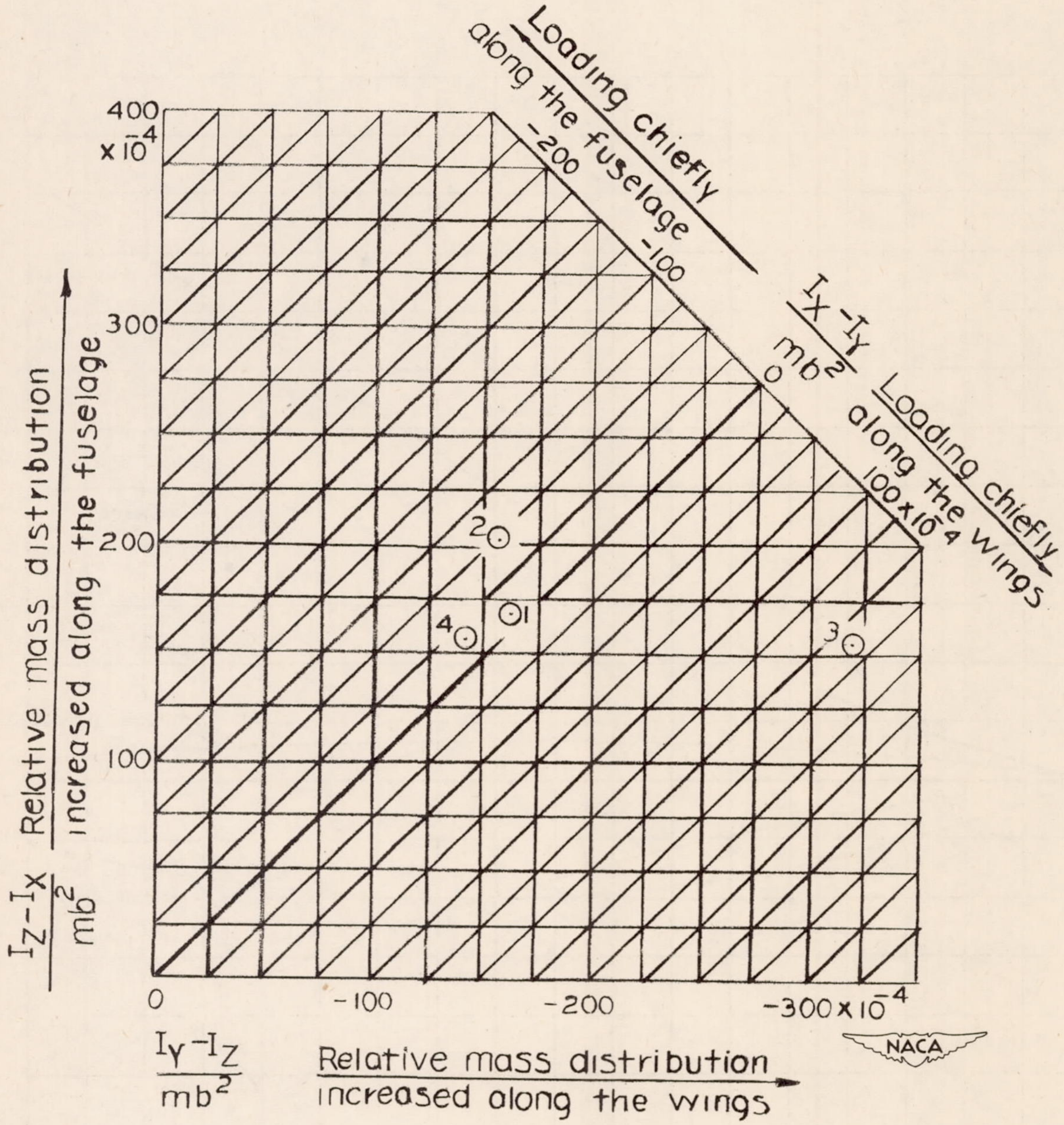


Figure 4.- Mass parameters for loadings tested on the model.

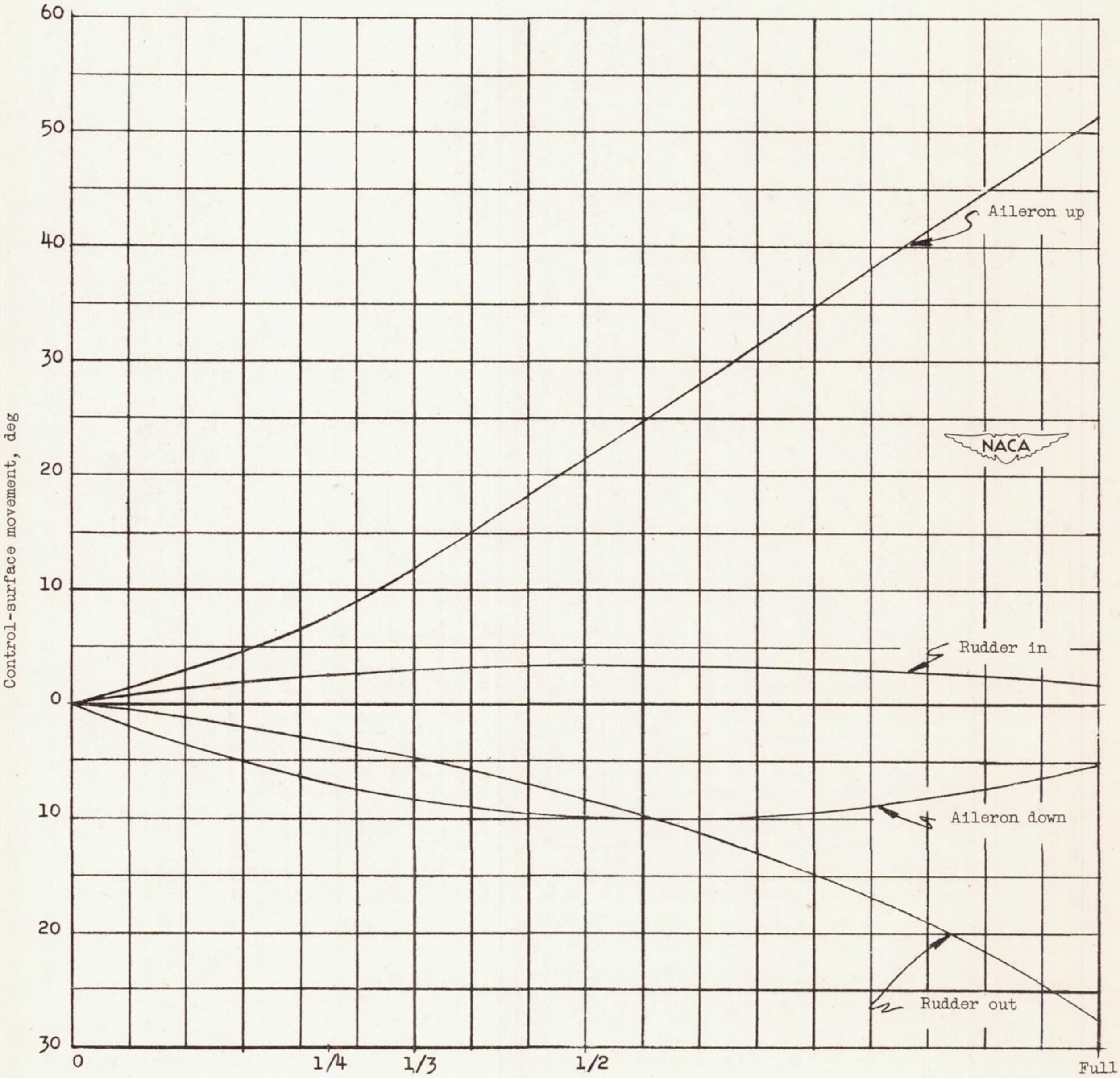


Figure 5.- Variation of rudder and aileron deflection with wheel position for the model as tested with linked rudder and aileron controls.

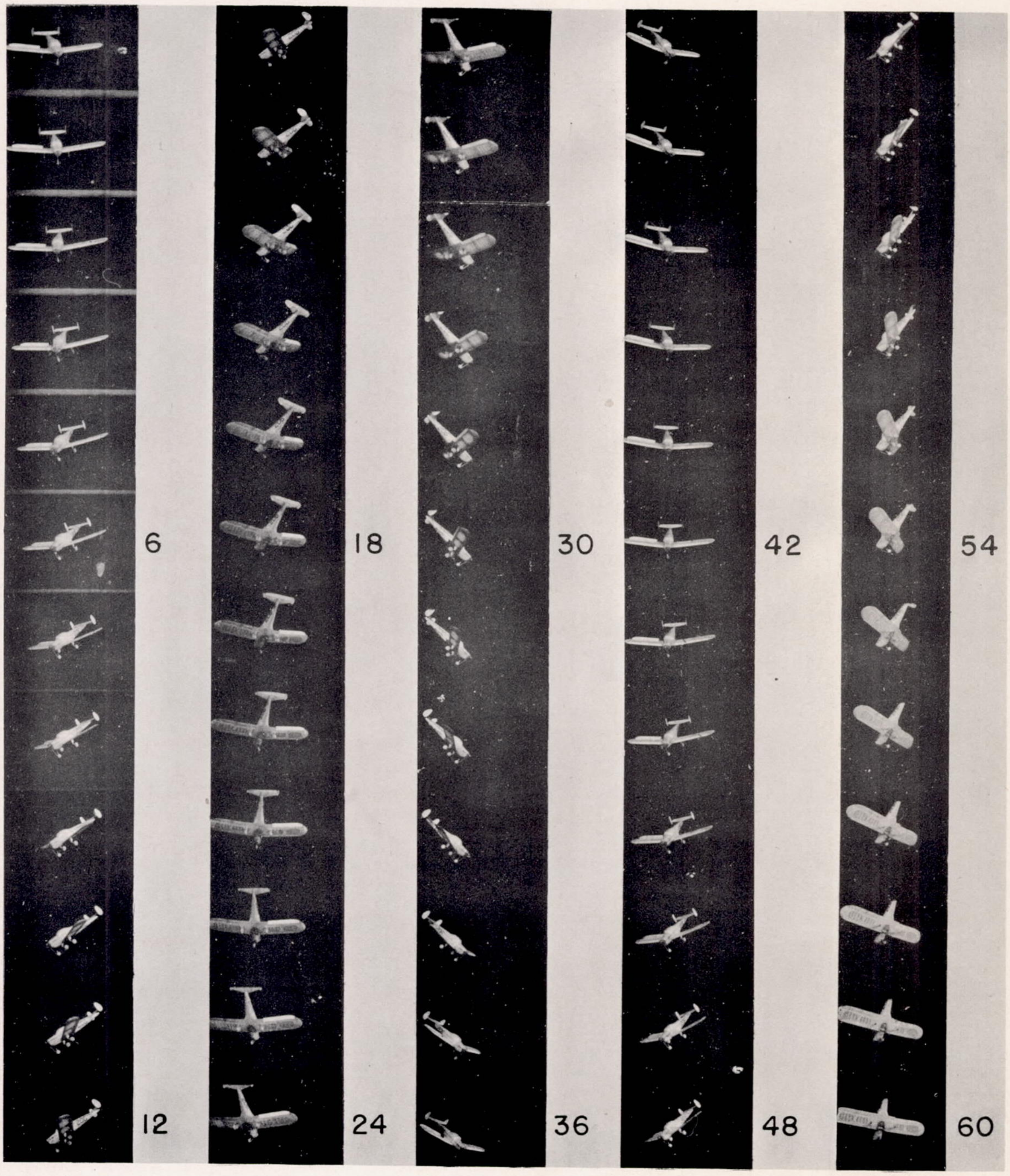


Figure 6.- Typical motion of the model with elevator deflected to 13° up and wheel set full with the spin (loading 3). Pictures taken at 64 frames per second.

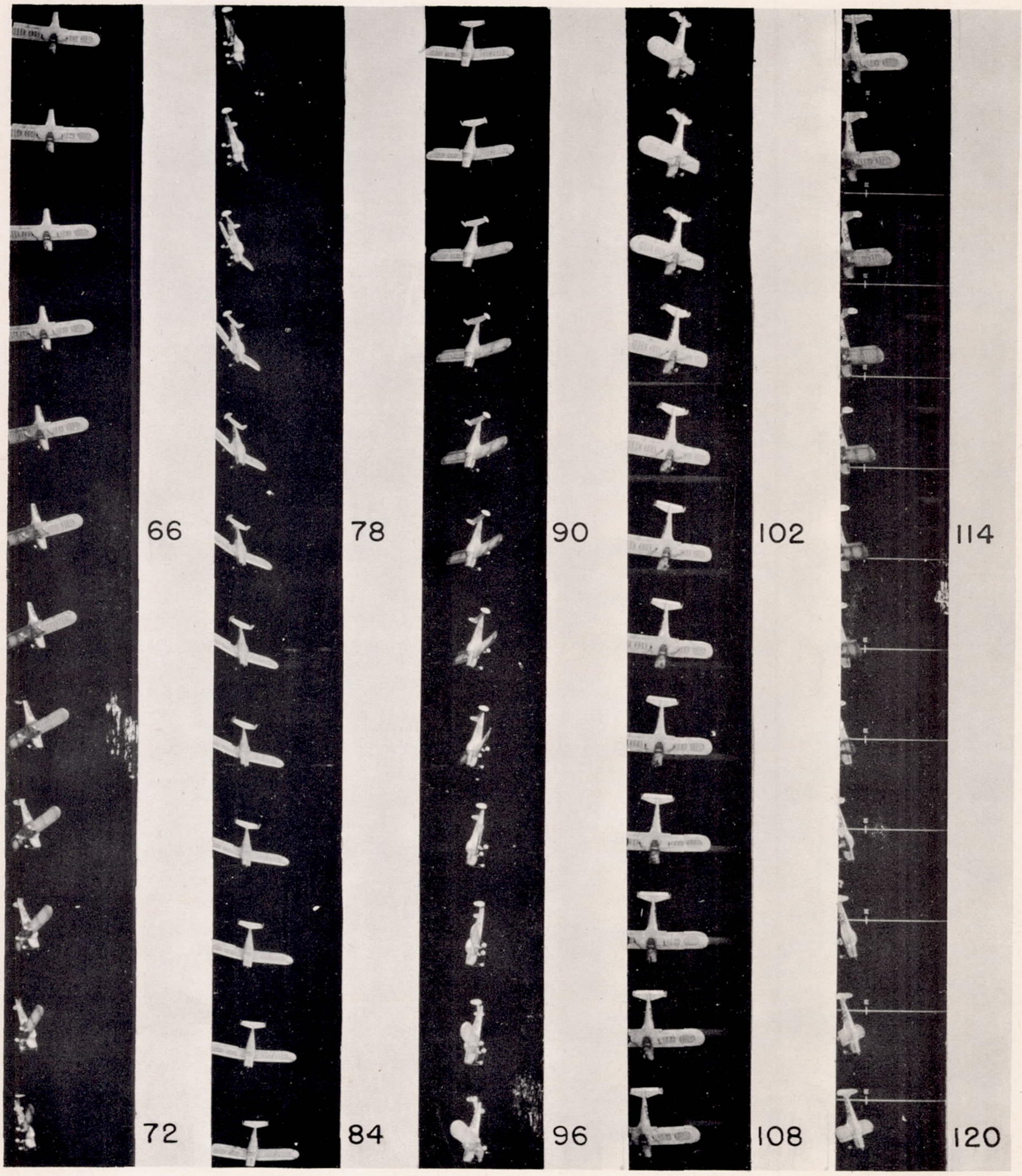


Figure 6.- Continued.

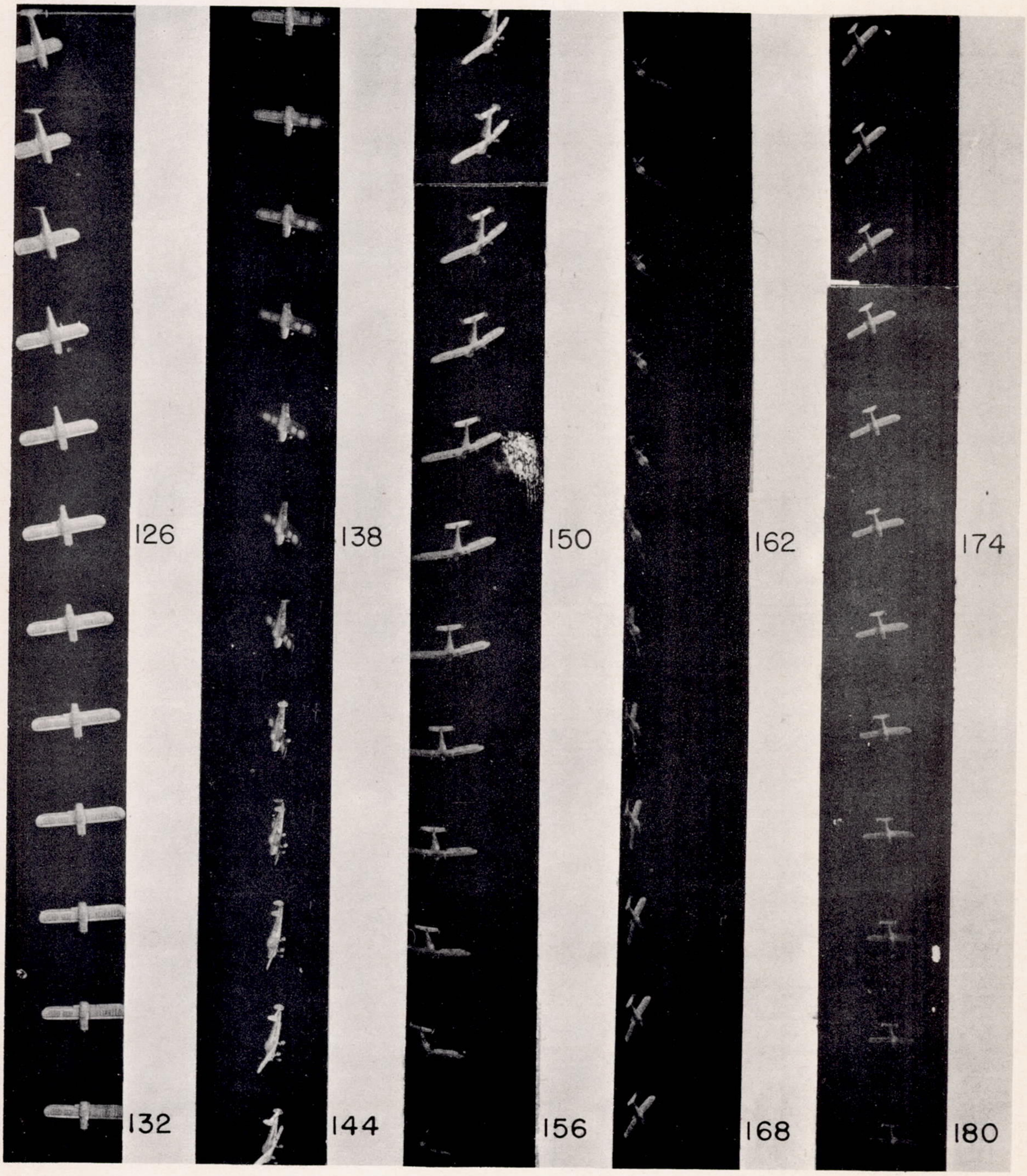


Figure 6.- Concluded.

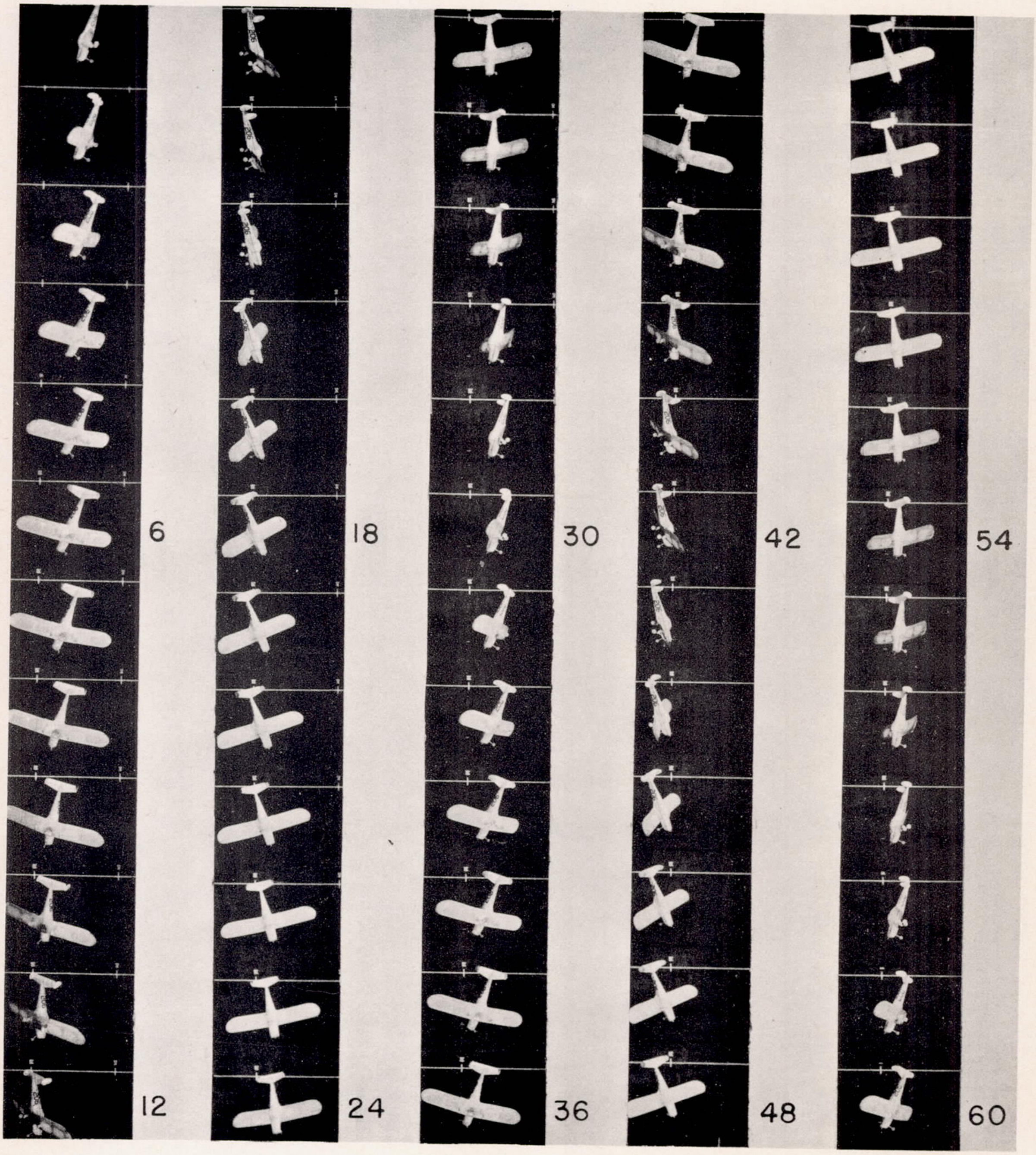


Figure 7.- Typical motion of the model with elevator deflected to 13° up and wheel set one-half with the spin (loading 2). Pictures taken at 64 frames per second.