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Spin-Tunnel Investigation of a 1/13-Scale Model of the NASA AD-1 Oblique-Wing Research Aircraft

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SUMMARY

An investigation has been made in the Langley Spin Tunnel to determine the spin and recovery characteristics of a 1/13-scale model of the NASA AD-1 oblique-wing research aircraft at wing-skew positions of 0° (conventional, unskewed position), 25°, 45°, and 60° (right wing forward). Spins were obtained for all wing-skew positions tested. For the unskewed wing position, two spin modes were possible. One spin mode was very steep and recoveries were obtained within 1 turn or less by rudder reversal. The second spin mode was flat and fast; the angle of attack was about 75° and the spin rate was about 145 deg/sec (2.5 seconds per turn).

For the skewed wing positions, spins were obtained only in the direction of the forward-skewed wing (right wing forward). No spins were obtained to the left when the wing was skewed with the right wing forward.

The aileron effect in a spin changed when the wing was skewed. Prospin ailerons changed from against the spin for the unskewed position to with the spin for wing-skewed positions. For the intermediate wing-skew positions, the spin was oscillatory with an angle of attack of about 60° to 85° and a spin rate about 145 to 170 deg/sec (2.5 to 2.1 seconds per turn). At 60° wing skew, the spin was smooth with an angle of attack of about 65° and a spin rate of about 100 deg/sec (3.6 seconds per turn).

Recoveries should be attempted by deflecting the rudder to full against the spin, the ailerons to full with the spin, and movement of the wings to 0° skew. If the wing is skewed, the recovery may not be effected until the wing skew approaches 0°.

INTRODUCTION

In cooperation with a NASA research program to provide fundamental aerodynamic and stability and control information on an aircraft configuration featuring an oblique wing, an investigation was made in the Langley Spin Tunnel to determine the spin and recovery characteristics of a 1/13-scale model of the NASA AD-1 oblique-wing research aircraft. The aircraft, which is a lightweight, single-place research vehicle, has a pivoting wing capable of moving obliquely from 0° unskewed to 60° (right wing forward). The investigation included erect spins and recoveries for spins to the right and left at the normal loading with wing-skew positions of 0°, 25°, 45°, and 60°.

SYMBOLS

b — wing span, ft

$\bar{c}$ — mean aerodynamic chord, ft

I_X, I_Y, I_Z — moment of inertia about X, Y, and Z body axis, respectively, slug-ft^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
m	mass, slugs
S	wing area, ft^2
V	full-scale rate of descent, fps
X,Y,Z	airplane body axes
x	distance of center of gravity rearward of leading edge of mean aerodynamic chord, ft
z	distance between center of gravity and fuselage reference line (positive when center of gravity is below line), ft
α	angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg
μ	airplane relative-density coefficient, $m/\rho Sb$
ρ	air density, $slugs/ft^3$
ϕ	angle between Y body axis and horizontal, measured in vertical plane, deg
Ω	full-scale angular velocity about spin axis, rps (seconds per turn)

MODEL

A 1/13-scale model of the NASA AD-1 oblique-wing research aircraft was built and prepared for testing by the Langley Research Center. A three-view drawing of the model is shown in figure 1. A photograph of the model with 0° wing skew is shown in figure 2(a). A composite photograph showing the wing in various wing-skew positions is shown in figure 2(b). The dimensional characteristics of the aircraft are presented in table I.

The model was ballasted to obtain dynamic similarity to the aircraft at an altitude of 10 000 ft with a value of relative-density coefficient μ of 12.0. The mass characteristics and inertia parameters for the typical loading at each wing-skew angle and the corresponding loading conditions tested on the model are presented in table II. Because it is impractical to ballast models exactly and because of inadvertent damage to models during tests, the measured weight and mass distribution of the model varied from the true scaled-down values within the following limits:

Weight, percent .... 2 to 4 high
Center-of-gravity location, percent $\bar{c}$ .... 0.2 to 1.0 rearward
Moments of inertia:
  I_X, percent .... 1.7 to 2.6 high
  I_Y, percent .... 3.6 to 3.6 high
  I_Z, percent .... 0.8 to 1.2 high

A radio-controlled system was used to actuate the control surfaces for the recovery attempts. Sufficient torque was exerted on the controls to reverse them fully and rapidly for the recovery attempts. The wing was also moved for some recovery attempts. The aircraft wing-skew position changes at the rate of 2 deg/sec and requires 30 sec for rotation through 60°. Because of the type of mechanism used in the spin-tunnel model, the wing rotated through 60° in about 1 sec (about 3 sec full-scale time). Therefore, during the tests where the wings were moved for recovery, the number of turns for recovery obtained on the model would be considerably less than would be expected on the aircraft. The normal maximum control-surface deflections (measured perpendicular to the hinge lines) for the full-scale aircraft and used on the model during the tests were as follows:

Rudder deflections, deg .... 25 right to 25 left
Elevator deflections, deg .... 25 up to 15 down
Aileron deflections, deg .... 25 up to 25 down
Wing skew, right wing forward, deg .... 0 to 60

SPIN-TUNNEL TESTS

The tests were made in the Langley Spin Tunnel, which is described in detail in reference 1. The test technique used in the tests is described in reference 1 and in the appendix of the present paper. The technique includes hand launching the model into the vertical airstream in a variety of attitudes (including a flat attitude) with spin rotation applied and allowing the model to enter an equilibrium condition or conditions, since there are often several spin modes possible for a particular configuration and loading.

Spin and recovery tests were conducted for erect spins to the pilot's right and left at 0°, 25°, 45°, and 60° wing-skew positions with a center-of-gravity location of 24 percent mean aerodynamic chord. As the wing rotated from 0° to 60°, the inertia yawing-moment parameter varied from -267×10^{-4} to -370×10^{-4}.

RESULTS

The results of the model spin tests are presented in charts 1 through 8. The model data are presented in terms of full-scale aircraft values for the aircraft at an altitude of 10 000 ft. The results for elevator up (stick back) are presented at the top of the chart, and results for elevator down (stick forward) are at the bottom of the chart. Results for ailerons with the spin (stick right in a right spin) are presented on the right side of the chart, and results for ailerons against the spin (stick left in a right spin) are on the left side of the chart. Adjacent to the block for "turns for recovery" on the chart is a symbol of a spin chart to show at a glance the positions of the elevator and ailerons for a given test. The "dot" on the symbol indicates the control position for the spin and the "arrow" gives the positions to which the controls were moved for recovery attempts. The criteria by which satisfactory recoveries are determined depend on the type of spin mode being analysed. For steep and/or oscillatory slow-rotating spins, model spin recoveries requiring approximately 2 turns or less are considered satisfactory. For high angle-of-attack spins (flat spins), where the spin rate is relatively fast, consistent recoveries of 4 turns or less are considered acceptable since the time and altitude lost during such recoveries are of the same order of magnitude as the time and altitude required for 2-turn recoveries from the slower spins. Also, 4 turns or less are considered acceptable only when the model exhibits an immediate response when the controls are moved for recovery, that is, on recovery-control movement the rate of rotation starts to gradually slow down and the angle of attack starts to decrease.

For recoveries from fast, flat spins that require slightly more than 4 turns, model results indicate that an airplane would probably recover, though slowly, with the resultant loss of too much altitude. Recoveries that require considerably more than 4 turns would be unsatisfactory, since altitude loss would be very high even if recovery should be obtained.

These criteria evolved from considerations of altitude lost in spins and correlations between model and full-scale tests for many fighter configurations.

0° Oblique Wing Position

The data for the 0° wing position are presented in chart 2 in terms of a right spin. The test results indicate no appreciable difference between left and right spins. A flat, fast spin mode was obtained when the ailerons were against the spin direction (stick left in a right spin). The angle of attack was about 78° and the spin rate was about 145 deg/sec (2.5 seconds per turn). A very steep spin occurred with the stick laterally neutral. The angle of attack of the spin was less than 30° and the rate of descent was greater than 200 ft/sec, exceeding the tunnel's airspeed capability and making quantitative data of the developed spin condition unachievable. Spins could not be obtained when the ailerons were deflected with the spin (stick right in a right spin). The applied launching rotation quickly damped and the model became oscillatory and entered a dive.

Various recovery control techniques were investigated, and although rudder reversal provided satisfactory recoveries from the very steep spin mode, the recoveries attempted with this technique from the flat, fast spin mode provided unsatisfactory results. The recovery control technique that provided the best results from the flat, fast spin mode was simultaneous movement of the rudder to full against the spin and the ailerons to full with the spin (stick right in a right spin) and should be satisfactory for any spin mode obtained at the conventional wing position.

25° Oblique Wing Position

Test results for the 25° oblique wing position (right wing forward) for right and left spin directions are presented in charts 3 and 4, respectively.

Spins to the pilot's right (into the forward-skewed wing) were obtained when the ailerons were against the spin (stick left), neutral, or with the spin (stick right). However, spins were easier to obtain and the rates of rotation were faster when the ailerons were against the spin. The spins were oscillatory, with the angle of attack approximately 70° to 85° and the spin rate about 170 deg/sec (2.1 seconds per turn) for the ailerons deflected against the spin. The spin rates were somewhat slower when the ailerons were deflected with the spins.

Various spin recovery-control techniques were investigated. Recoveries attempted with rudder full against the spin or with simultaneous movement of the rudder to full against the spin and the ailerons to full with the spin (stick right) were unsatisfactory. Satisfactory recoveries were obtained by simultaneously moving the rudder to full against the spin, the ailerons to full with the spin (stick right), and the wings to 0° position (unskewed wing position).

Attempts to obtain spins to the pilot's left (into the rearward-skewed wing) were unsuccessful. As the applied rotation damped, the model steepened and entered a dive.

45° Oblique Wing Position

Test results with the 45° oblique wing position (right wing forward) for spins to the pilot's right and left are presented in charts 5 and 6, respectively.

Spins to the pilot's right (into the forward-skewed wing) were obtained easily at all elevator positions when the ailerons were with the spin (stick right) and fairly easily when the ailerons were neutral. The model did not spin or was reluctant to spin when the ailerons were against the spin (stick left).

The spins obtained to the right are presented in chart 5. The spins were oscillatory; however, there was a general tendency for the inner wing to be noticeably higher than the outer wing. The angle of attack varied between about 60° and 85° and the spin rate was about 145 deg/sec (2.5 seconds per turn). Spins attempted with ailerons against the spin resulted in very oscillatory motions, and the model oscillated out of the spin motion quickly.

Recoveries attempted by full rudder reversal were very slow. The apparent satisfactory recovery by this method, noted at the elevator-up (stick back) and ailerons-against (stick left) spin condition, is questionable in that the nature of the spin was such that the model may well have oscillated out of the spin at the time the rudder moved. Since the model did not spin when the ailerons were deflected to against the spin, recoveries were attempted by deflecting the rudder to against the spin and the ailerons to against the spin. No recoveries were obtained.

Recoveries could be obtained from the spin condition where the ailerons were with the spin (stick right) by simultaneous movement of the rudder to full against the spin and the wing to the unskewed position. The rapid recovery obtained with the model does not represent the recovery characteristics that would be obtained with the aircraft because of the difference in time for wing-skew changes between the model and aircraft. Based on the aircraft rate of wing-skew change of 2 deg/sec, the model wing-skew change from 45° to 0° should have required about 6 sec; however, the spin-tunnel model changed wing skew from 45° to 0° in less than 1 sec.

Spins could not be obtained to the pilot's left (into the rearward-skewed wing), as presented in chart 6. As the applied spin rotation damped, the model either entered a glide or steepened and entered a dive.

60° Oblique Wing Position

Test results with the 60° oblique wing position for spins to the pilot's right and left are presented in charts 7 and 8, respectively.

Spins to the pilot's right (into the forward-skewed wing) were readily obtained when the ailerons were with the spin (stick right). However, when the ailerons were against the spin (stick left), the applied rotation damped and the model entered a glide.

Two types of spins were indicated from the model tests. The most likely spin was smooth with an angle of attack of about 65 degrees and a spin rate of about 100 deg/sec (3.6 seconds per turn). The second spin possible was oscillatory with the angle of attack varying between about 55° and 75° and a spin rate of about 85 deg/sec (4.2 seconds per turn). In both the smooth and the oscillatory spins, the model spun with the inner wing up about 20° to 28°.

Recoveries were attempted by deflecting the rudder to against the spin and simultaneously deflecting the rudder and ailerons to against the spin, and by deflecting the rudder to against the spin while simultaneously moving the wing to 0° skew position. No satisfactory recoveries were obtained by any of these recovery techniques. The fastest recoveries were obtained by deflecting the rudder and moving the wing. The model results indicated that the aircraft would recover about the time the wings approached 0° skew (about 8 to 10 turns). The model recovered considerably faster because the wing on the model rotated faster than the rate corresponding to the aircraft.

Attempts to obtain spins to the pilot's left (into the rearward-skewed wing) were unsuccessful. As the launching rotation damped, the model slowed and either entered a dive or a glide (chart 8).

OBLIQUE-WING EFFECTS

Test results at 0°, 25°, 45°, and 60° oblique wing positions presented in charts 2, 3, 5, and 7 for spins to the pilot's right (into the forward swept wing) show that as the wing position progressively increased from 0° to 60° skew, the model exhibited a progressively greater tendency to spin when the ailerons were maintained with the spin (stick right) and a progressively lesser tendency to spin when the ailerons were maintained against the spin (stick left).

Test results for spins to the pilot's left (into the rearward-skewed wing), presented in charts 2, 4, 6, and 8 for the 0°, 25°, 45°, and 60° oblique wing positions, show that spins which had been obtained at the 0° wing position became unobtainable at the 25°, 45°, and 60° wing positions. The model quickly damped the launching rotation and either slowed and entered a dive or glide or, in some instances, built up oscillations and rolled out.

Another phenomenon, which was slightly apparent at the 25° and 45° wing positions and very apparent at the 60° wing position, occurred when the model entered a glide. The model, when gliding, had the relative wind along the wing-chord line while the fuselage was at a large sideslip angle.

The wing position affected the recovery technique. At the 0° wing position, recoveries attempted with the simultaneous movement of rudder to full against the spin and ailerons to full with the spin, which is the normal recovery technique for aircraft of this type, provided satisfactory recoveries. However, since ailerons with the spin became prospin as the wing skew was increased, this technique became unsatisfactory at the 25° wing position, and, at larger wing-skew positions, the aileron-with control deflection had a prospin effect on the spin.

Movement of the wing position to 0° in conjunction with moving the rudder to full against the spin and the ailerons to full with the spin resulted in recoveries from spins obtained with all wing skew positions. Since this technique was effective only when the wing was moved fully to 0°, it should be expected that the recovery motion would not be apparent until the wing approached this position.

The time factor in these tests for movement of the wing to 0° was about 1 sec on the model, during which time the model rotated between 1/2 and 3/4 of a turn. The time required to move the wing from 60° to 0° on the aircraft is expected to be about 30 sec. Therefore, the time to move from 60° to 0° wing position for the model should require about 8 sec rather than the 1 sec. Because of the faster wing-skew rate on the model, the model indicated faster recoveries than will be experienced on the aircraft. The aircraft recoveries will probably be about 10 turns rather than the 1 1/2 turns indicated by the model.

RECOMMENDED RECOVERY TECHNIQUE

The recommended recovery technique for erect spins on this aircraft is simultaneous movement of the rudder to full against the spin, the ailerons to full with the spin, and (if the wing is not in the conventional wing position) move the wing angle to 0°.

CONCLUSIONS

Results of a spin-tunnel investigation on the NASA AD-1 oblique-wing research aircraft at 0°, 25°, 45°, and 60° wing positions (right wing forward) are summarized as follows:

1. For the unskewed wing position (0° wing skew), two spin modes were indicated based on model results. One spin mode was very steep and recoveries by full rudder reversal were obtained within 1 turn or less. The second spin mode was flat and fast, with an angle of attack of about 78° and a spin rate of about 145 deg/sec (2.5 seconds per turn).

2. Recoveries for the unskewed wing position in a flat spin should be attempted by deflecting the rudder to full against the spin, the ailerons to full with the spin, and the elevator to neutral. Recoveries with this technique may be slow.

3. For the skewed wing positions, spins were indicated possible only in the direction of the forward-skewed wing (right wing forward in spin to the right). No spins were indicated possible to the left when the wing was skewed right wing forward.

4. The prospin aileron effect changed from aileron against for the 0° wing-skew position to ailerons with for the 60° wing-skew position.

5. Spins were obtained at all other wing-skew positions tested from 25° to 60°. For the 25° wing-skew position, the spin was oscillatory between angles of attack of about 70° to 85° and the spin rate was about 170 deg/sec (2.1 seconds per turn). For the 45° wing-skew position, the spin was oscillatory between angles of attack of about 60° to 85° and the spin rate was about 145 deg/sec (2.5 seconds per turn). For the 60° wing-skew position, the spin was usually smooth with the angle of attack about 65° and the spin rate about 100 deg/sec (3.6 seconds per turn).

6. Recoveries attempted from the wing-skew conditions indicated that the aircraft may not recover from the spin by rudder reversal and deflecting ailerons to full with or to full against the spin, especially for wing-skew positions of 45° and higher.

7. Recovery can be obtained from the wing-skew conditions by simultaneously deflecting the rudder to full against the spin, the ailerons to full with the spin, and the wing to the 0° skew position; however, up to 10 turns may be required for recovery since recovery is not obtained until the wing approaches the 0° wing position.

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APPENDIX

TEST METHODS AND PRECISION

Model Testing Technique

General descriptions of spin model testing techniques, methods of interpreting test results, and correlation between model and airplane results are presented in reference 1.

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a model for a matrix of control settings in various combinations, including neutral and maximum settings of the surfaces. Recovery is generally attempted by rapid full reversal of the rudder, by rapid full reversal of both rudder and elevator, or by rapid full reversal of the rudder simultaneously with the movement of the elevator to neutral and the roll control to full with the spin. Tests are conducted for the various possible loading conditions of the airplane because the control manipulation required for recovery is generally dependent on the mass and the geometric characteristics of the model (ref. 1).

Tests are sometimes performed to evaluate the possible adverse effects on recovery of small deviations from maximum or neutral control settings. For these tests, the elevator is set at either full-up deflection or two-thirds of its full-up deflection, and the lateral controls are set at one-third of full deflection in the direction conducive to slower recoveries, which may be either against the spin (stick left in a right spin) or with the spin, depending primarily on mass characteristics of the particular model. Recovery is attempted by rapidly reversing the rudder from full with the spin to only two-thirds against the spin, by simultaneous rudder reversal to two-thirds against the spin and movement of the elevator to either neutral or two-thirds down, or by simultaneous rudder reversal to two-thirds against the spin and lateral stick movement to two-thirds with the spin. This control configuration and manipulation is referred to as the "criterion spin," with the particular control settings and manipulation used being dependent on the mass and geometric characteristics of the model.

Turns for recovery are measured from the time the controls are moved to the time the spin rotation ceases. Recovery characteristics of a model are generally considered satisfactory if recovery attempted from all spins in any of the manners previously described is accomplished within 2 1/4 turns. For some airplane designs, especially some high-performance fighters, recoveries that require somewhat more than 2 1/4 turns but that can be obtained consistently may be considered satisfactory, or at least acceptable. The results of tests of such a model have to be evaluated fully, considering the results of each such case, and no hard and fast rule stating an exact maximum number of turns allowed can be adopted in advance of the model tests. Modern high-performance fighter configurations are considerably different from the configurations studied in reference 1 wherein the 2 1/4 turn recovery criterion was applicable. Modern fighter aircraft are generally designed such that the fuselage has a relatively long forebody, which has an added aerodynamic influence on the spin, and a vertical tail which is usually shielded from effective airflow at high angles of attack. The mass characteristics are such that the fuselage is heavily loaded relative to the wings and the relative density μ is considerably higher than those of models referred to in reference 1. These design characteristics cause the roll control (ailerons and/or differential horizontal tail) to become the primary recovery control, rather than the rudder.

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Because of the differences in airplane design, mass characteristics, and the primary control required for recovery, the 2 1/4 turn recovery criterion cannot be used to evaluate the recovery characteristics of present-day fighter aircraft. With fighter aircraft, where roll control (ailerons and/or differential horizontal tail) is the primary recovery control, experience has indicated that model recoveries from steep and/or oscillatory spins with a relatively slow spin rate in approximately 2 turns are considered satisfactory. However, for high angle-of-attack spins (flat spins), where the spin rate is relatively fast, consistent recoveries in 4 turns or less are considered acceptable since the time and altitude lost during such recoveries would be of the same order of magnitude as the time and altitude lost in 2-turn recoveries from slower, steeper spins.

For spins in which a model has a rate of descent in excess of that which can readily be obtained in the tunnel, the rate of descent is recorded as greater than the velocity at the time the model hit the safety net, for example, >300 ft/sec full scale. In such tests, the recoveries are attempted before the model reaches its final steeper attitude and while it is still descending in the tunnel. Such results are considered conservative; that is, recoveries are generally not as fast as when the model is in the final steeper attitude. For recovery attempts in which a model strikes the safety net while it is still in a spin, the recovery is recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, for example, >3. A >3-turn recovery, however, does not necessarily indicate an improvement over a >7-turn recovery. A recovery in 10 or more turns is indicated by ∞. When a model loses the rotation applied at launch within a few turns and recovers without control movement (rudder and other controls held with the spin), the results are recorded as "no spin."

For spin-recovery parachute tests, the parachute system required to effect satisfactory recovery is determined. The parachute is deployed for the recovery attempts by actuating a remote-control mechanism, and the controls are maintained prospin so that recovery is due to the parachute action alone.

Precision

Results determined in free-spinning tunnel tests are believed to be true values given by models within the following limits:

α, deg	±1
ϕ, deg	±1
V, percent	±5
Ω, percent	±2
Turns for recovery obtained from motion-picture records	±1/4
Turns for recovery obtained visually during test	±1/2

The preceding limits may be exceeded for certain spins in which the model is difficult to control in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

APPENDIX

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

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

Controls are set within an accuracy of ±1°.

REFERENCE

1. Neihouse, Anshal I.; Klinar, Walter J.; and Scher, Stanley H.: Status of Spin Research for Recent Airplane Designs. NASA TR R-57, 1960. (Supersedes NACA RM L57F12).

TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE NASA AD-1 AIRCRAFT

Total height, ft	6.75
Total length, ft	38.8
Wing (0° wing skew):	
Reference and actual planform area, ft^2	93
Reference and unswept span, ft	32.3
Reference and unswept chord (root), ft	4.28
Aspect ratio	11.2
Airfoil	NACA 3612 (modified)
Dihedral angle, deg	0
Twist, deg	-2
Root incidence angle, deg	2
Quarter-chord sweep angle, deg	0
Leading-edge sweep angle, deg	2
Average chord, ft	2.9
Wing pivot location	0.4
Skew range, deg	0 to 60
Horizontal tail:	
Planform area, ft^2	26
Span, ft	8
Average chord, ft	3.3
Root chord, ft	5.4
Dihedral angle, deg	0
Incidence angle, deg	0
Leading-edge sweep angle, deg	45
Airfoil	NACA 0006
Vertical tail:	
Area (exposed), ft^2	14.4
Span (exposed), ft	3.7
Average chord, ft	3.9
Root chord, ft	5.8
Leading-edge sweep angle, deg	43
Airfoil	NACA 0006

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR VARIOUS LOADINGS

[Values given are full scale; moments of inertia are given about the center of gravity]

Loading	Angle of wing skew, deg	Weight, lb	Center-of-gravity location		Relative density, μ, at -		Moments of inertia, slug-ft^2			Mass parameters		
			$x/\bar{c}$	$z/\bar{c}$	Sea level	10 000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Aircraft												
1	0	1955	0.240	0	8.50	11.51	671	2361	2984	-267×10^{-4}	-98×10^{-4}	365×10^{-4}
2	25	1955	.240	0	8.50	11.51	586	2448	2985	-294	-85	379
3	45	1955	.240	0	8.50	11.51	433	2601	2985	-342	-60	403
4	60	1955	.240	0	8.50	11.51	314	2720	2885	-380	-42	422
Model												
1	0	2032	0.245	0.045	8.86	12.00	655	2401	2975	-267×10^{-4}	-88×10^{-4}	355×10^{-4}
2	25	2032	.247	.045	8.86	12.00	573	2469	2981	-290	-78	368
3	45	2032	.249	.045	8.86	12.00	421	2630	2986	-338	-54	392
4	60	2032	.250	.045	8.86	12.00	308	2727	2980	-370	-39	408

CHART 1.- FOOTNOTES FOR CHARTS OF SPIN AND RECOVERY CHARACTERISTICS

OF THE NASA AD-1 AIRCRAFT

[a]Recovered in a dive.

[b]Recovery attempted by simultaneous movement of the rudder to full against the spin and the elevators to full down.

[c]Recovery attempted by rudder full against the spin.

[d]Recovery attempted by simultaneous movement of the rudder to full against the spin and the ailerons to full with the spin.

[e]As the applied rotation damped, the model steepened very quickly, and the rate of descent increased at a rate that exceeded the accelerative capabilities of the tunnel.

[f]Recovery attempted by full rudder reversal as the model was steepening.

[g]As the applied rotation damped, the model became oscillatory and entered a dive.

[h]Recovered in an almost vertical dive and began to roll with the rudder.

[i]Two conditions possible.

[j]As the applied rotation damped, the model steepened and entered a dive.

[k]Oscillatory spin. Range or average of values given.

[ℓ]Recovery attempted by simultaneous movement of the rudder to full against the spin, the ailerons to full with the spin, and the wing skew to 0°.

[m]Recovery attempted by simultaneous movement of the rudder full against the spin and the wing skew to 0°.

[n]Wing moved to 0° skew during spin (controls maintained in prospin positions); the spin smoothed to a steady spin as in the unskewed wing condition.

[o]As the applied rotation damped, the model slowed and entered a glide

[p]As the applied rotation damped, the model built-up oscillations and rolled into an inverted glide.

[q]Recoveries on the aircraft are expected to be 8 to 10 turns greater than those of the model because the rate of wing movement is relatively slow compared with that of the model.

[r]Recoveries attempted by simultaneous movement of the rudder to full against the spin and the ailerons to full against the spin.

[s]As the applied rotation damped, the model entered a glide with the relative wind across the wing chord line and the fuselage at a large sideslip angle.

[t]Recovered in a glide with the relative wind across the wing and the fuselage at a large sideslip angle.

[u]Spin is alternately steady and oscillatory for 2 to 3 turns. Average or range of values given.

[v]Recovery attempted during oscillatory phase of spin.

[w]Recovery attempted by simultaneous movement of the rudder to full against the spin and the wing moved to 45° skew.

Chart 2.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL FOR LOADING 1

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading 1 (see table II)		
XF-1	Erect	Right or left		$\frac{I_X - I_Y}{mb^2} = -267 \times 10^4$	
0° wing skew			Center-of-gravity position 0.245c̄	Altitude 10 000 ft	

Model values converted to full scale U-inner wing up D-inner wing down Numbers outside blocks indicate test numbers.

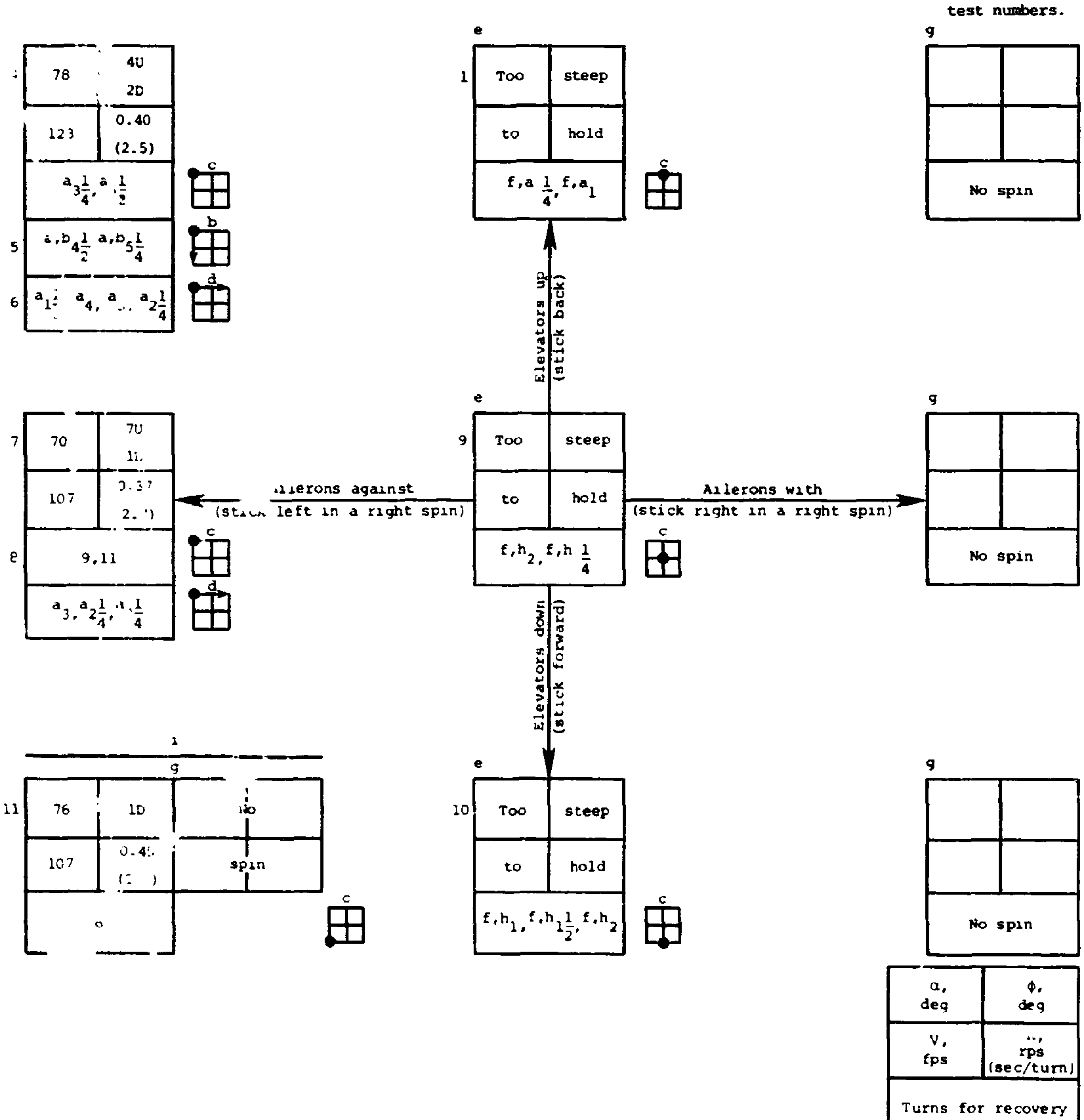


CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL FOR LOADING 2 IN A RIGHT SPIN

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading 2 (see table II)	$\frac{I_X - I_Y}{mb^2} = -290 \times 10^{-4}$	
AD-1	Erect	Right, into the forward-skewed wing			
25° wing skew	Flaps		Center-of-gravity position 0.247$\bar{c}$	Altitude 10 000 ft	

Model values converted to full scale U-inner wing up D-inner wing down Numbers outside blocks indicate test numbers.

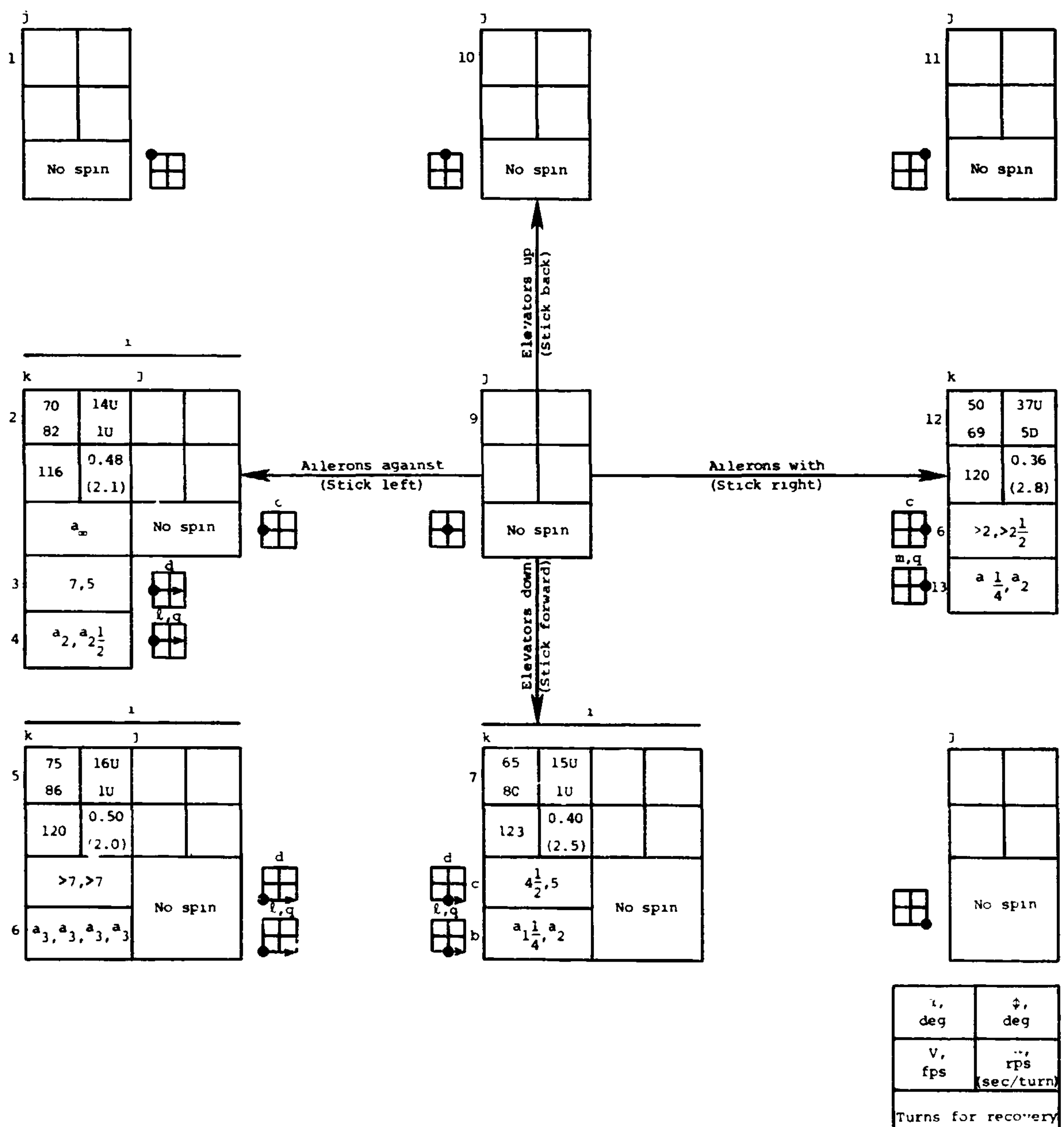


CHART 4.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

FOR LOADING 2 IN A LEFT SPIN

[Data presented for rudder-full-with spins]

Airplane AD-1	Attitude Erect	Direction Left, into the rearward-skewed wing	Loading 2 (see table II)	$\frac{I_X - I_Y}{mb^2} = -290 \times 10^{-4}$	
25° wing skew			Center-of-gravity position 0.247c̄	Altitude 10 000 ft	

Model values converted to full scale   U-inner wing up   D-inner wing down   Numbers outside blocks indicate test numbers.

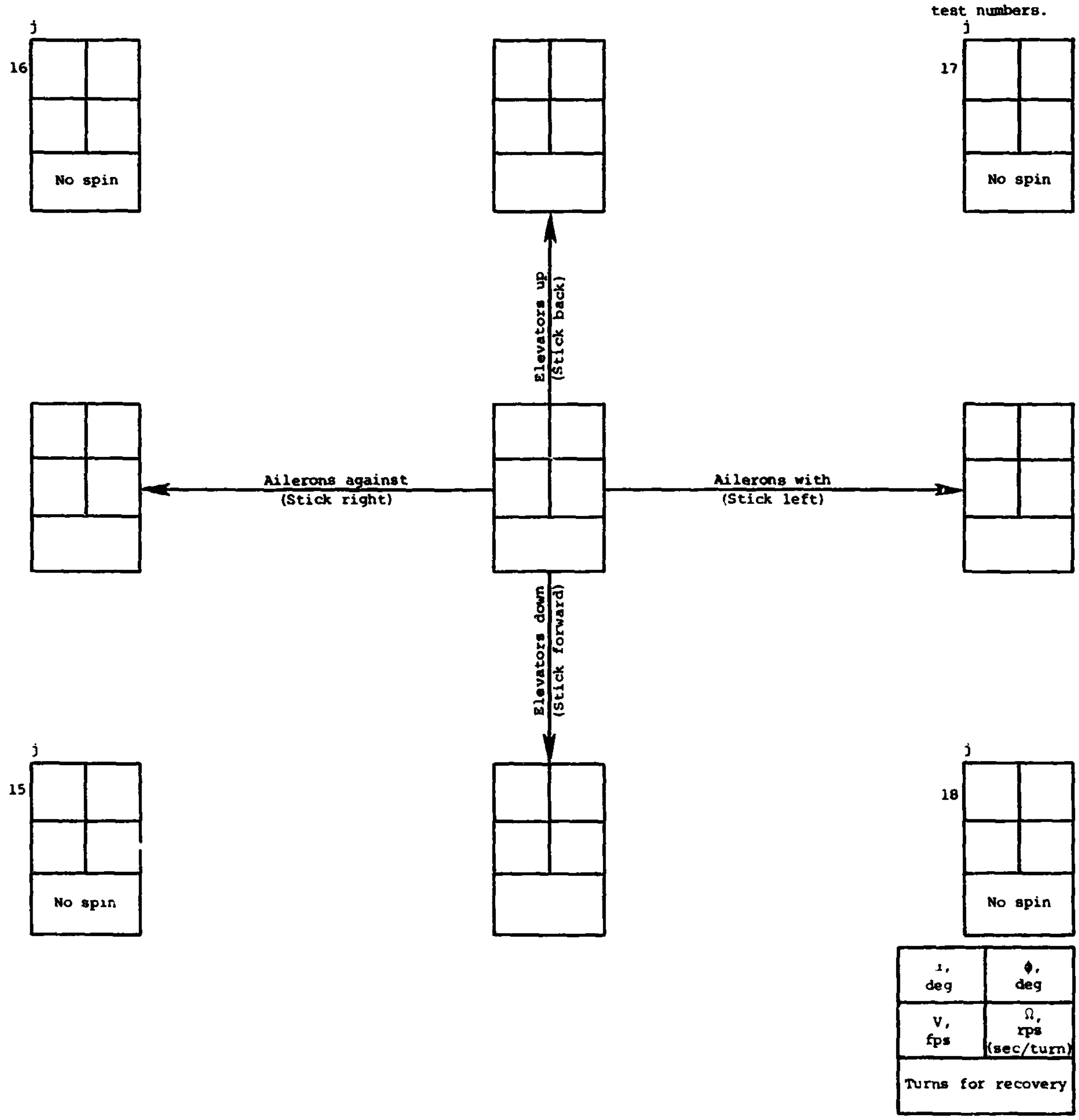


CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL FOR

LOADING 3 IN A RIGHT SPIN

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading 3 (see table II)		$\frac{I_X - I_Y}{mb^2} = -338 \times 10^{-4}$
AD-1	Erect	Right, into the forward-skewed wing			
45° wing skew			Center-of-gravity position 0.249c̄	Altitude 10 000 ft	

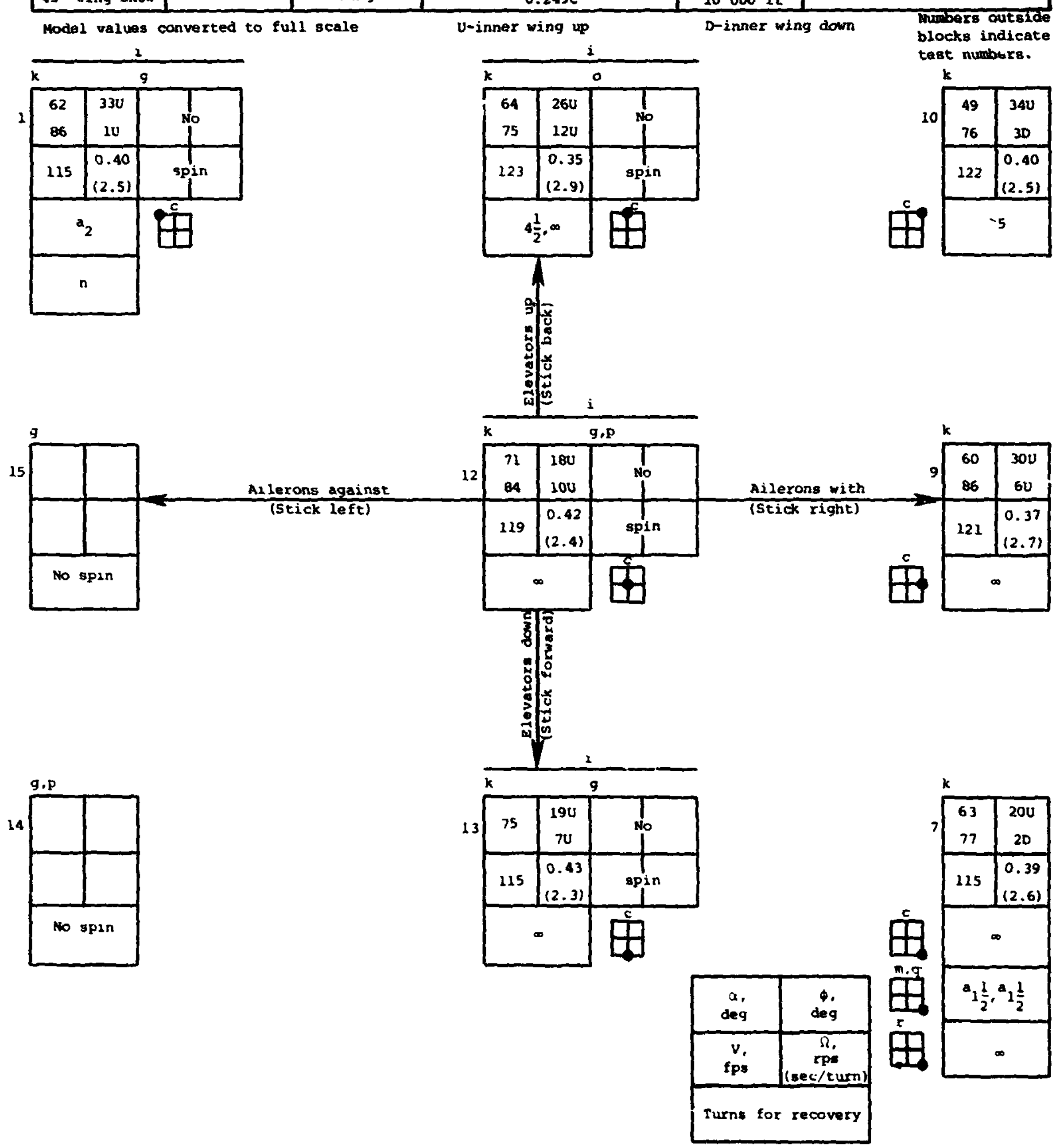


CHART 6.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL FOR

LOADING 3 IN A LEFT SPIN

[Data presented for rudder-full-with spins]

Airplane AD-1	Attitude Erect	Direction Left, into the rearward-skewed wing	Loading 3 (see table II)	$\frac{I_X - I_Y}{mb^2} = -338 \times 10^{-4}$	
45° wing skew			Center-of-gravity position 0.249$\bar{c}$	Altitude 10 000 ft	

Model values converted to full scale   U-inner wing up   D-inner wing down   Numbers outside blocks indicate test numbers.

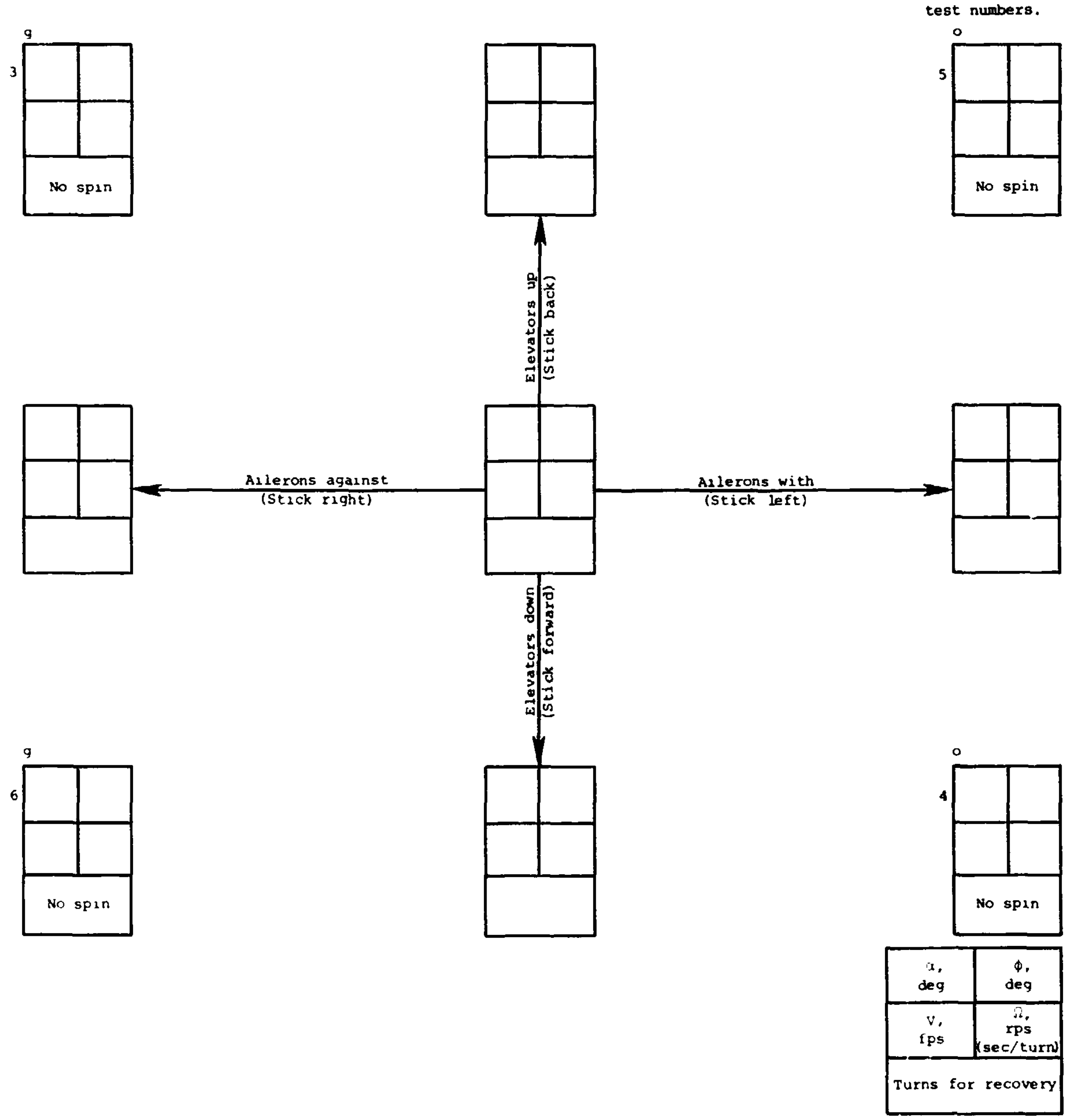


CHART 7.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL FOR

LOADING 4 IN A RIGHT SPIN

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed spin data presented for, rudder-full-with spins)]

Airplane	Attitude	Direction	Loading 4 (see table II)		$\frac{I_X - I_Y}{mb^2} = -370 \times 10^{-4}$
AD-1	Erect	Right, into the forward-skewed wing			
60° wing skew			Center-of-gravity position 0.245c̄	Altitude 10 000 ft	

Model values converted to full scale U-inner wing up D-inner wing down Numbers outside blocks indicate test numbers.

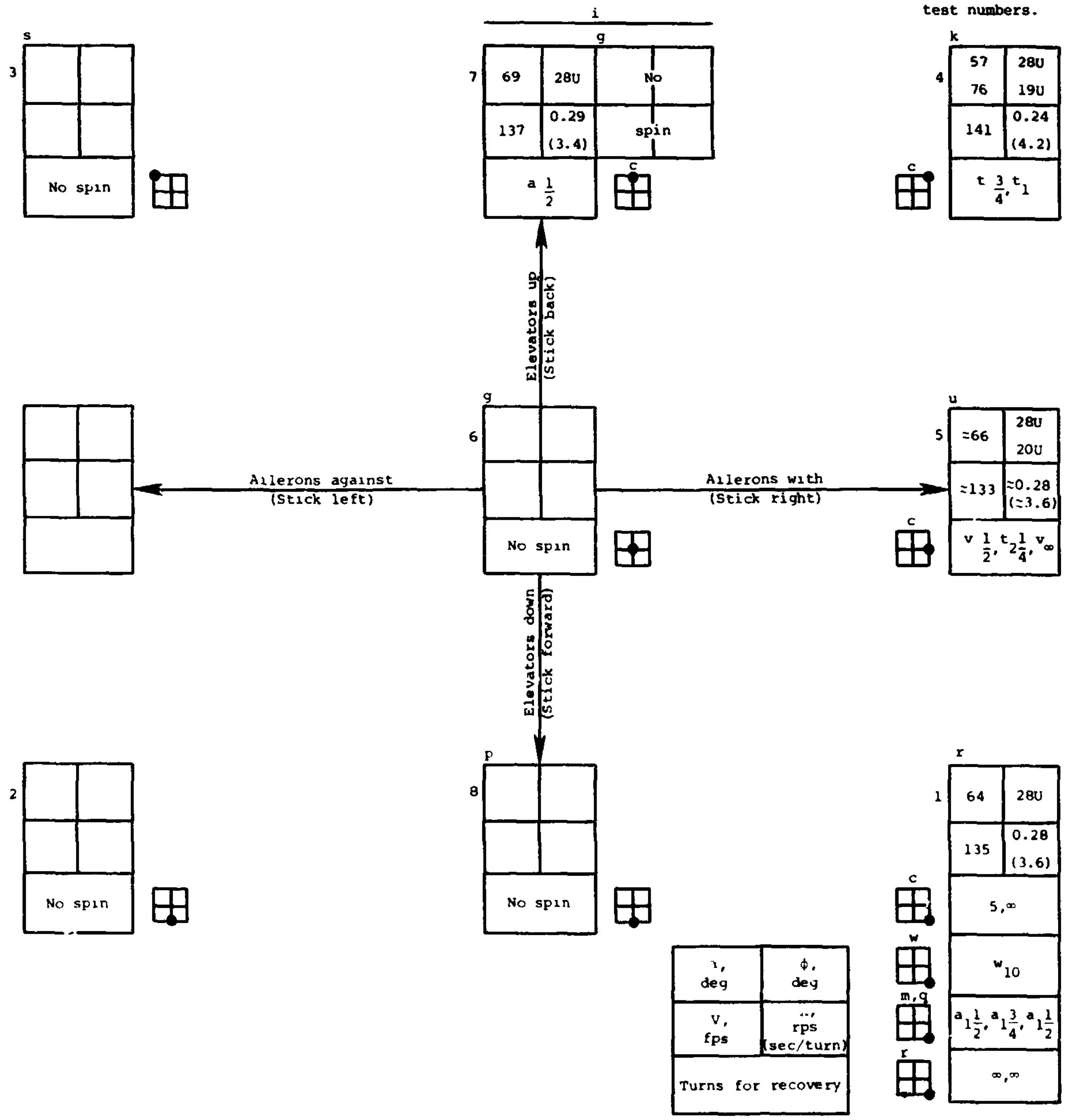


CHART 8.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL FOR LOADING 4 IN A LEFT SPIN

[Data presented for rudder-full-with spins]

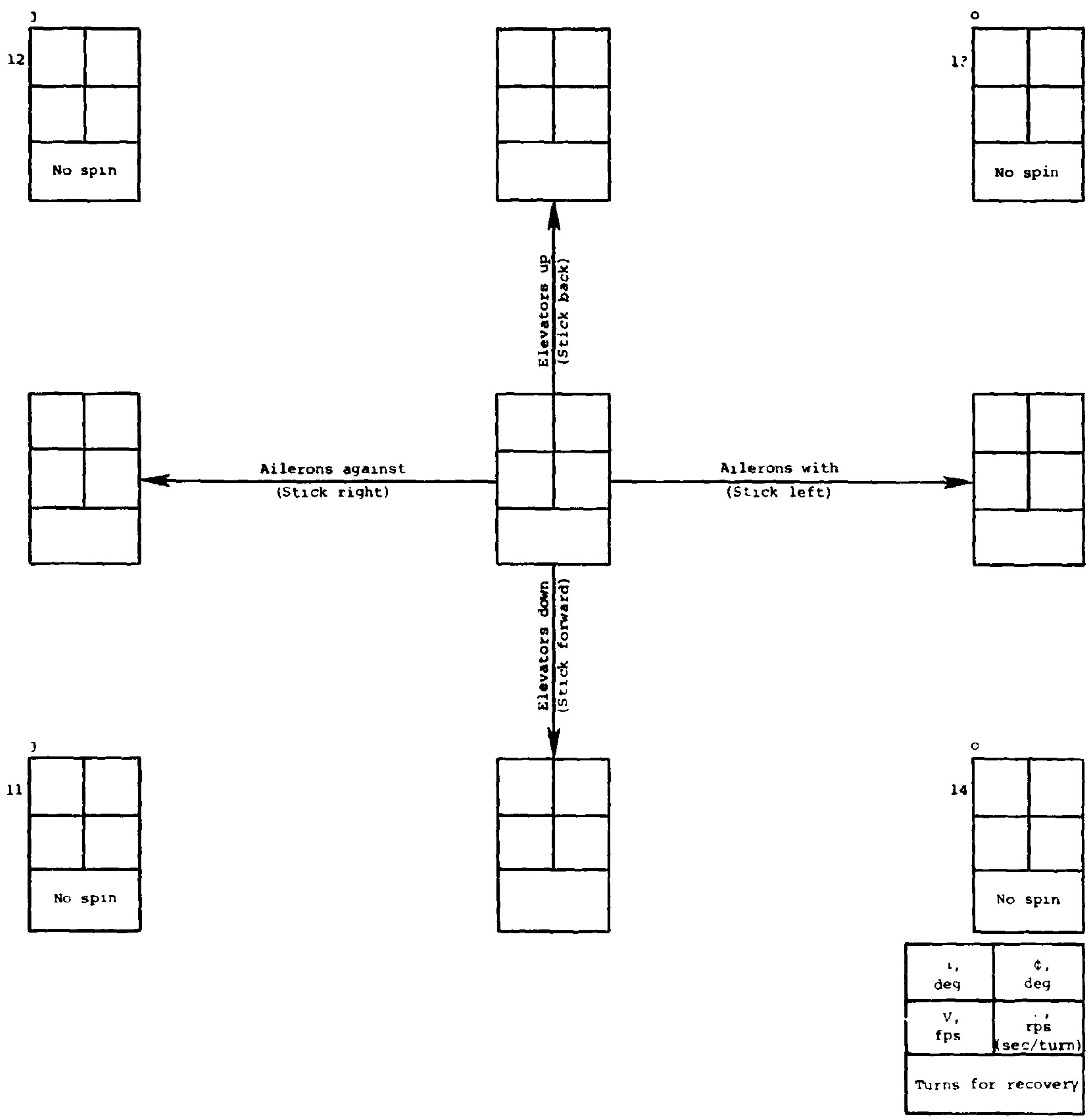
Airplane	Attitude	Direction	Loading 4 (see table II)		$\frac{I_X - I_Y}{mb^2} = -370 \times 10^{-4}$
AD-1	Erect	Left, into the rearward-skewed wing			
60° wing skew			Center-of-gravity position 0.245$\bar{c}$	Altitude 10 000 ft	

Model values converted to full scale

U-inner wing up

D-inner wing down

Numbers outside blocks indicate test numbers.



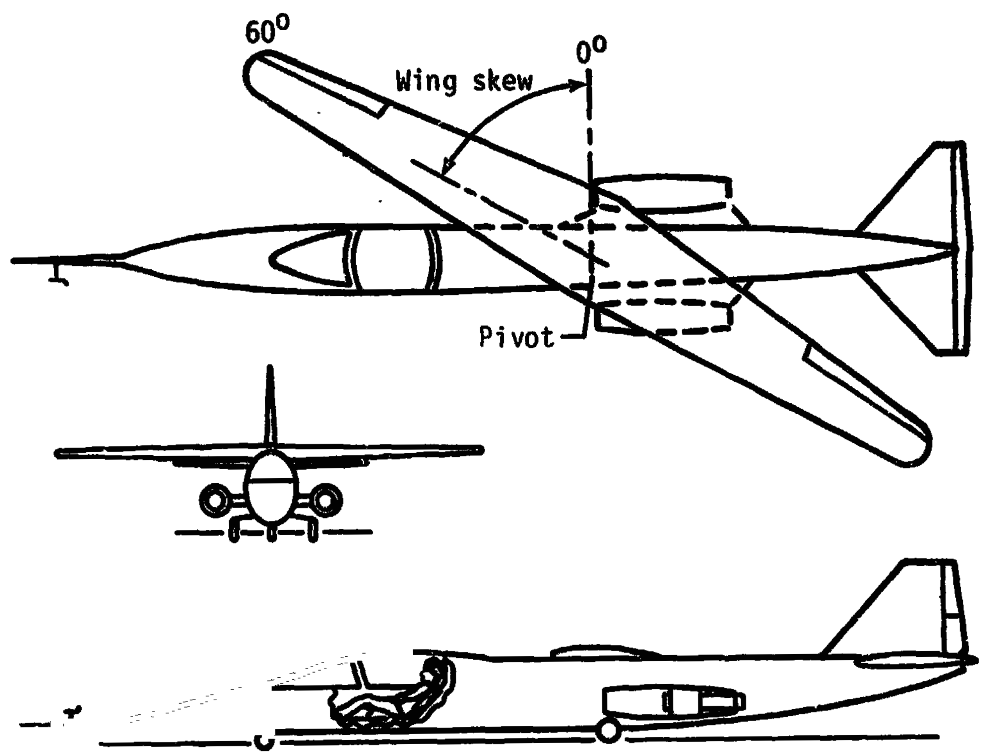


Figure 1.- Three-view drawing of test configuration.

L-80-2553

(a) 0° wing skew.

Figure 2.- Photograph of test model

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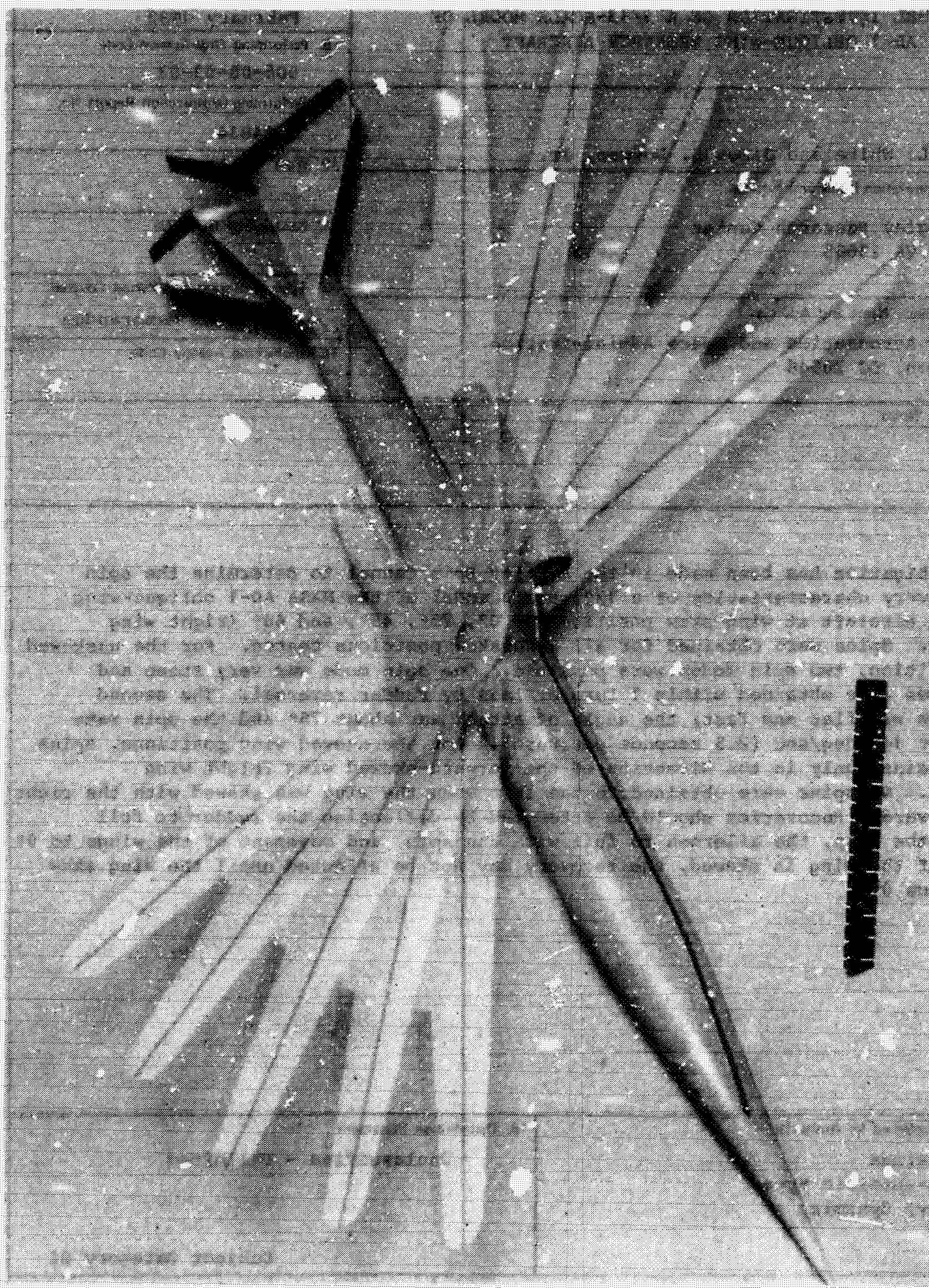

L-80-2200

(b) Wing-skew positions.