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SPIN INVESTIGATION OF A 1/20-SCALE MODEL OF AN UNSWEPT-WING, TWIN-ENGINE, OBSERVATION AIRPLANE

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SPIN INVESTIGATION OF A 1/20-SCALE MODEL OF AN UNSWEPT-WING, TWIN-ENGINE, OBSERVATION AIRPLANE

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SUMMARY

An investigation was conducted in the Langley 20-foot free-spinning tunnel on a 1/20-scale model of an unswept-wing, twin-engine, observation airplane. The effects of control settings and movements on the erect spin and recovery characteristics for the normal loading and the most rearward center-of-gravity loading (external wing tanks full) were determined. Also, tests were made to determine the effect on the spin and recovery characteristics of a large radar store, of empty and full external wing tanks, and of an asymmetrical condition when one empty or one full external wing tank is carried. Spin-recovery parachute tests were also performed.

The results of the tests indicate that erect spins obtained on the airplane for the normal loading should be satisfactorily terminated by rudder reversal to full against the spin, ailerons moved to with the spin, followed one-half turn later by forward movement of the stick to neutral. With the radar store, with wing tanks empty, or with an asymmetrical condition when one empty tank is on either wing, satisfactory recoveries can be obtained by using the same technique as for the normal loading. Recoveries for the model with a rearward center-of-gravity loading (external wing tanks full) or with a full tank on the wing inboard of the spin axis will be slow to unsatisfactory with rudder reversal to full against the spin followed by brisk forward stick movement. With a full tank on the wing outboard of the spin axis, the recoveries will be satisfactory. Spins in the landing configuration should be terminated by first retracting the flaps, slats, and landing gear, after which recovery should be attempted immediately by using the recovery technique recommended for the normal loading condition. Inverted spins can be satisfactorily terminated by rudder reversal to full against the spin followed by neutralization of the longitudinal and lateral controls. A 12.5-foot-diameter tail parachute with a towline length of 21.7 feet and a drag coefficient of 0.65 should be satisfactory for recoveries from erect and inverted demonstration spins when used simultaneously with movement of rudder to neutral.

INTRODUCTION

An investigation has been made in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of a model of a typical observation airplane. The model was representative of a 1/20-scale model of a midwing, twin-turboprop-engine aircraft with an unswept wing and three vertical tails.

The erect spin and recovery characteristics of the model were determined for the normal loading and for the most rearward center-of-gravity loading (external wing tanks full). Tests were also made to determine the effect of asymmetrical loading with one wing tank on, either full or empty. For the normal loading configuration, tests were made to determine the effect of a side-looking airborne radar on the model, and in addition tests were made for the landing configuration. The inverted spin and recovery characteristics of the model were determined for the normal loading.

An appendix includes a general description of the model testing technique, information on the precision with which model test results and mass characteristics are determined, and a general comparison of dynamic model and full-scale spin tests, based on past experience with other designs. In addition, variations of the model mass characteristics occurring during the tests are presented.

SYMBOLS

b	wing span, ft
$\bar{c}$	mean aerodynamic chord, ft
C_D	parachute drag coefficient
I_X,I_Y,I_Z	moments of inertia about X, Y, and Z body axes, 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 of airplane, slugs
S	wing area, sq ft
V	full-scale true rate of descent, fps
x	distance of center of gravity rearward of leading edge of mean aerodynamic chord

z distance between center of gravity and fuselage reference line (positive when center of gravity is below line)

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

μ relative density of airplane, $m/\rho Sb$

ρ air density, slugs/cu ft

ϕ angle between span axis and horizontal, deg

Ω full-scale angular velocity about spin axis, rps

MODEL

A 1/20-scale model typical of an unswept-wing observation airplane was built and prepared for testing at the Langley Research Center of the National Aeronautics and Space Administration. A photograph showing the model in the normal flying configuration is shown in figure 1. A three-view drawing of the model is shown in figure 2. The dimensional characteristics of the full-scale airplane are presented in table I.

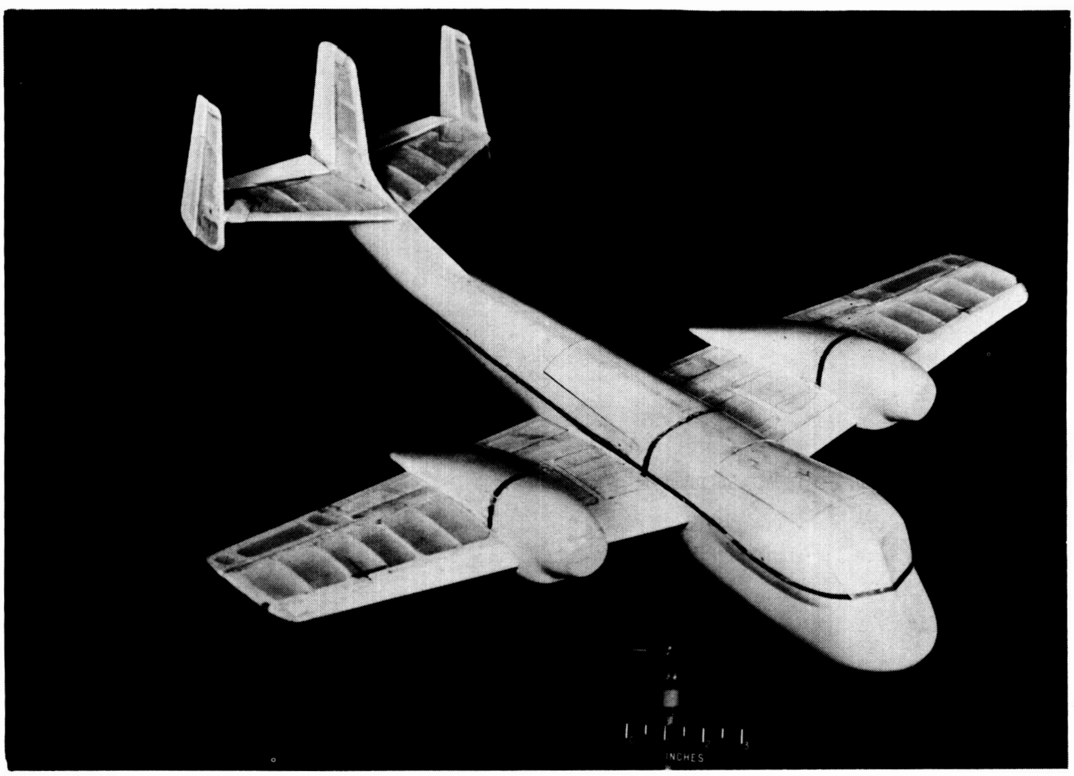


Figure 1. - The 1/20-scale model of twin-engine observation airplane as tested in the Langley 20-foot free-spinning tunnel. L-59-282

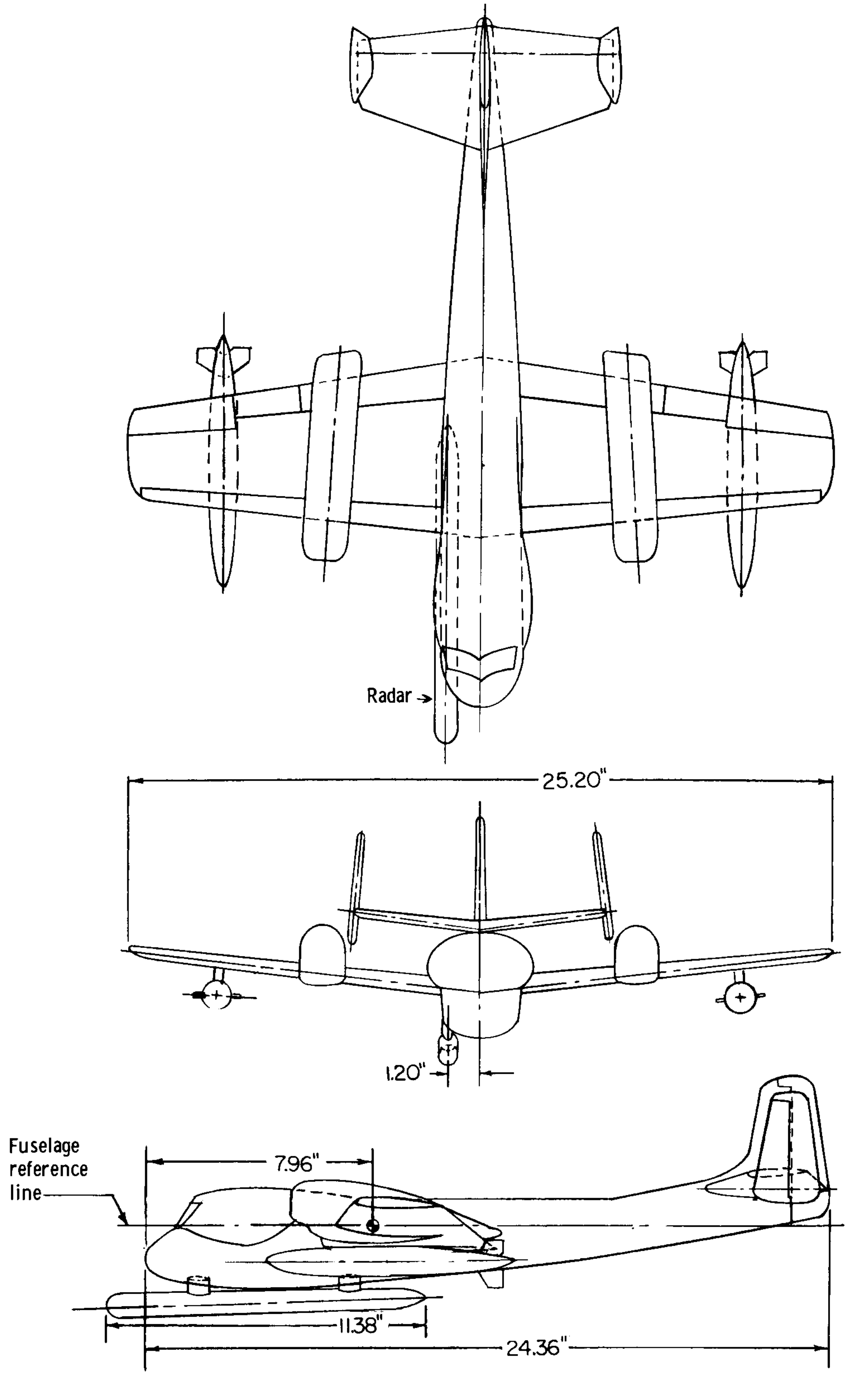


Figure 2. - Three-view drawing of 1/20-scale model of twin-engine observation airplane tested in Langley 20-foot free-spinning tunnel. Center-of-gravity position shown is for normal loading.

TABLE I.- FULL-SCALE DIMENSIONAL CHARACTERISTICS OF THE FULL-SCALE OBSERVATION AIRPLANE

Overall length, ft	40.60
Wing:	
Span, ft	42.00
Area, sq ft	330.00
Mean aerodynamic chord, in.	98.00
Root chord, in.	126.00
Tip chord, in.	63.00
Taper ratio	0.50
Aspect ratio	5.35
Sweep of 0.40 chord line, deg	0
Airfoil section	NACA 2412
Incidence, deg	1.5
Dihedral, deg	6.5
Flap area (total), sq ft	43.6
Deflected-aileron area (total), sq ft	17.5
Aileron area (total), sq ft	22.7
Leading-edge slat area (total), sq ft	41.0

Horizontal tail:	
Area, sq ft	85.0
Span, ft	15.92
Aspect ratio	2.65
Sweep of 0.75 chord line	0
Taper ratio	0.50
Root chord, in.	90.6
Tip chord, in.	45.3
Airfoil section	NACA 0012
Dihedral, deg	6.5
Elevator area (total), sq ft	19.0

	Inboard	Outboard
Vertical tails:		
Area, sq ft	25.8	21.5
Aspect ratio (one tail)	1.64	2.06
Sweep of 0.55 chord line, deg	0	0
Taper ratio	0.54	0.46
Root chord, in.	61.5	53.0
Tip chord, in.	33.5	24.5
Airfoil section	NACA 0012	NACA 0012
Rudder area, sq ft	11.32	9.5

The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 18,000 feet (ρ = 0.001355 slug/cu ft). Mass characteristics and mass parameters for loadings possible on the airplane and for the loading conditions tested on the model are presented in table II. A remote-control mechanism was installed in the model to actuate the controls for the recovery attempts. Sufficient torque was exerted on the controls to reverse them fully and rapidly for the recovery attempts.

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE LOADINGS OF THE FULL-SCALE AIRPLANE AND FOR THE LOADINGS TESTED ON THE 1/20-SCALE MODEL

[Values given are full scale, and moments are given about the center of gravity]

Number	Loading	Weight, lb	Center-of-gravity location		Relative density, μ		Moments of inertia, slug-ft^2			Mass parameters		
			$x/\bar{c}$	$z/\bar{c}$	Sea level	18,000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_X - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane values												
1	Normal	10,423	0.250	-----	9.82	17.24	14,790	21,411	33,579	-116×10^{-4}	-213×10^{-4}	329×10^{-4}
2	Most rearward center of gravity (with full external wing tanks)	11,037	0.304	-----	10.40	18.25	29,346	19,844	47,141	157×10^{-4}	-451×10^{-4}	294×10^{-4}
3	Most forward center of gravity	9,249	0.231	-----	8.71	15.29	12,557	18,853	27,670	-124×10^{-4}	-174×10^{-4}	298×10^{-4}
4	Nominal center of gravity	12,347	0.231	-----	11.63	20.41	13,131	20,687	32,069	-112×10^{-4}	-168×10^{-4}	280×10^{-4}
Model values												
1	Normal	10,602	0.243	0.051	9.98	17.52	21,266	28,777	47,248	-129×10^{-4}	-318×10^{-4}	447×10^{-4}
2	Most rearward center of gravity	10,351	0.290	0.061	9.74	17.09	30,686	24,549	51,985	108×10^{-4}	-485×10^{-4}	376×10^{-4}

The maximum control deflections normally used on the model during the tests (measured perpendicular to the hinge lines) were:

Rudder, deg	25 right, 25 left
Elevator, deg	25 up, 15 down
Ailerons, deg	25 up, 25 down
Flaps:	
Inboard, deg	45 down
Outboard, deg	25 down

RESULTS AND DISCUSSION

The results of the spin tests of the model are presented in charts 1 to 4 and in table III. The model data are presented in terms of full-scale values for the airplane at an altitude of 18,000 feet. Inasmuch as the results for right and left spins were generally similar, the data are presented arbitrarily in terms of right spins. Propellers were not simulated on the model, but on the basis of spin-tunnel experience, the results presented are considered to be generally applicable for the airplane spinning either to the right or to the left with idling propellers. Because of the gyroscopic effect of the two propellers turning clockwise (as viewed from pilot's seat) it may be difficult for the airplane to enter right spins; however, when right spins are obtained they may be slightly steeper than corresponding left spins.

Erect Spins

On the charts, results for elevator up (stick back) are presented at the top of the chart and results for elevator down (stick forward), 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 (stick left), on the left side of the chart.

Normal loading.- The results of the erect spin tests in the normal loading (loading 1, in table II) and clean condition with a center-of-gravity position of $0.25\bar{c}$ are presented in chart 1. In general, the results indicate that the spins were at a moderate attitude (α approx. 55°) and relatively steady with a fairly fast rate of rotation (about 3 seconds per turn, full scale). The data presented indicate that for all control settings used, except for ailerons against the spin and elevator neutral or down, satisfactory recoveries were obtained by reversal of rudder to full against the spin. With ailerons set with the spin (stick right in a right spin) the spins were steep and the recoveries were rapid. For the normal control spin configuration (that is, elevator full up, ailerons neutral and rudder full with), two types of spins were possible, a normal-attitude spin and a steep spin. Satisfactory recoveries were obtained from either spin. Satisfactory recoveries were also obtained from the criterion spin (ailerons one-third against the spin and elevators two-thirds up) when the rudder was reversed to two-thirds (17°) against the spin. The criterion spin is used in order to evaluate more fully the recovery characteristics for the normal control spin configuration by determining the effect of relatively small control variations from the normal-control spin configuration. This is explained fully in reference 1. For all recoveries when recovery appears imminent, the stick should be moved to neutral to prevent entry into a secondary spin in the opposite direction. Brief tests were made in the normal loading to determine the effect on the spin and recovery characteristics of empty external wing tanks on both wings, or of a single tank on either the wing outboard or the wing inboard of the spin axis. The results (not presented in chart form) indicated no adverse effects from the tanks. Brief tests were also made in the normal loading with a side-looking airborne radar store mounted under the right side of the fuselage (fig. 2). The spins obtained were generally steep with rapid recoveries. However, the recoveries from the normal-attitude spin were marginal $\left(2 \text{ to } 2\frac{1}{2} \text{ turns}\right)$ when rudder movement to full against the spin was used.

Rearward center-of-gravity loading (full external wing tanks).- The results of the erect spin tests for the most rearward center-of-gravity loading (external wing tanks full; loading 2, in table II) are presented in chart 2. With the full external wing tanks on, the loading is chiefly along the wings; and the spins obtained with ailerons set with the spin were flatter than those obtained for the normal loading. With the ailerons set against the spin, no spins only were obtained. No satisfactory recoveries were obtained from the criterion spin (ailerons 1/3 with the spin and elevators 2/3 up) when the rudder was reversed to 2/3 (17°) against the spin. Because of structural considerations it is not advisable to spin the airplane with any full external tank installed. Therefore, if the airplane should enter a spin with either or both external tanks full, the tanks should be jettisoned immediately and recovery attempted by the technique recommended for the normal loading.

No spin charts are presented for the tests with the rearward center-of-gravity loading to determine the effect on the spin and recoveries of the asymmetrical condition with only one full external wing tank on. The results obtained indicated that the recoveries from the spins with a tank on the wing outboard of the spin axis were satisfactory for all loading conditions. However, the recoveries in the criterion spin with a tank on the wing inboard of the spin axis were unsatisfactory.

Landing configuration.- Tests made in the normal loading (loading 1, table II) for the landing configuration (with slats open and flaps down) are presented in chart 3. The spins obtained were generally flat and the recoveries by full rudder reversal were unsatisfactory. Based on the criterion spin, the recovery characteristics of the model in this configuration are considered unsatisfactory. If the airplane should enter a spin in the landing configuration, it is recommended that the flaps be retracted immediately and recovery attempted by the procedure specified for the normal loading.

Inverted Spins

Brief tests were made on the model to determine the inverted-spin and recovery characteristics and the results of these tests are presented in chart 4. The order used for presenting the data in this chart for inverted spins is different from that used for erect spins. For inverted spins, data for controls crossed for the established spin (right rudder pedal forward and stick to the pilot's left for a spin with rotation to the pilot's right) are presented to the right of the chart, and stick-back data are presented at the bottom. When the controls are crossed in the established spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion. The angle of wing tilt ϕ in the chart is given as up (U) or down (D) relating to the ground.

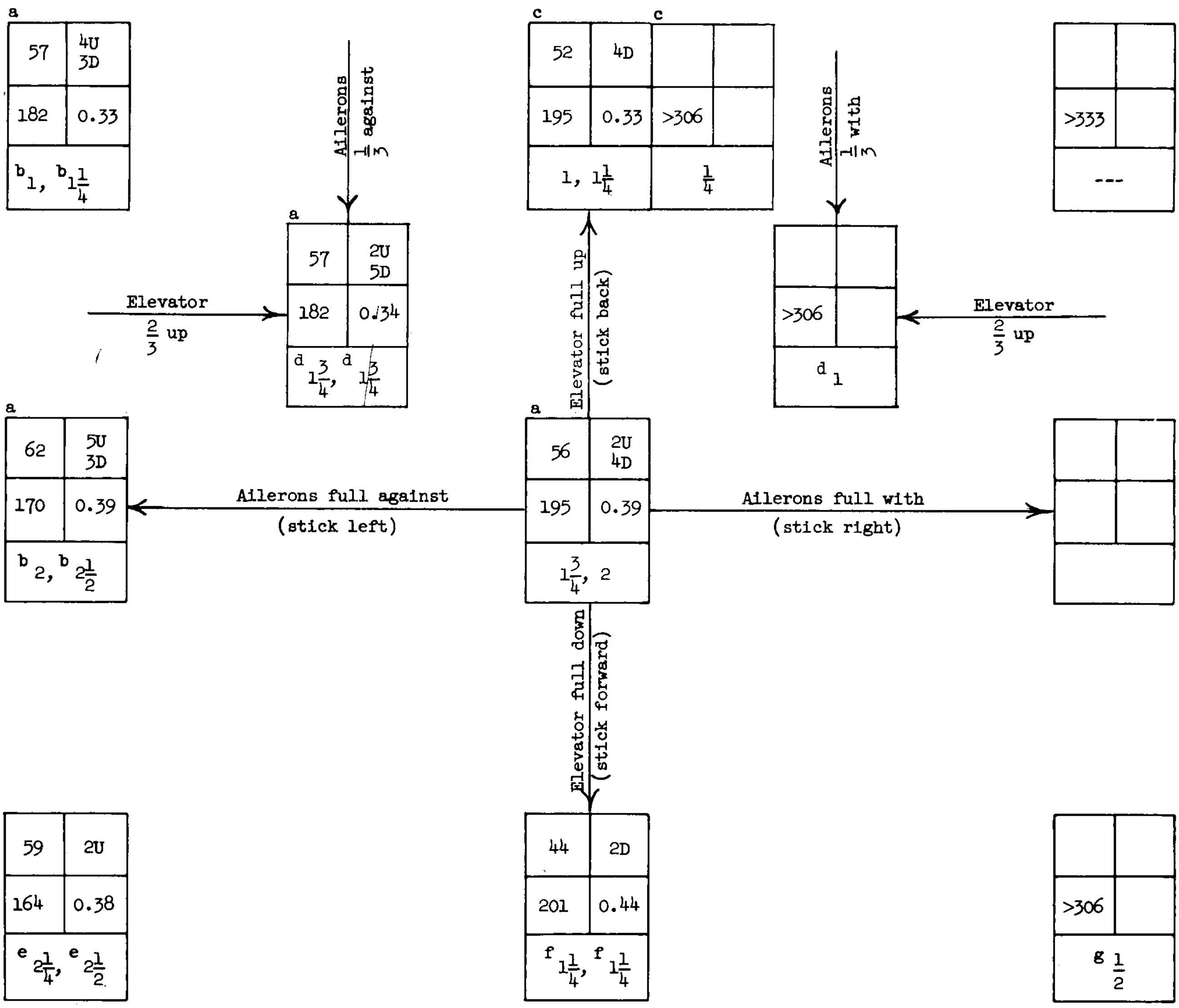
The tests were made for the normal loading (loading 1, table II). The results indicate that the spins were very steep with a fast rate of rotation.

CHART 1 .— SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

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

Airplane, Observation	Attitude, Erect	Direction, Right	Loading (see table II) No. 1		Normal loading
Slats, Closed	Flaps, Up		Center-of-gravity position, 25 percent $\bar{c}$	Altitude, 18,000 ft	Clean condition

Model values converted to full scale U–inner wing up D–inner wing down



[a]Oscillatory spin, range or average values given.
[b]Model went into a steep aileron roll to left.
[c]Two conditions possible.
[d]Recovery by reversal of rudder to $\frac{2}{3}$ against spin.
[e]Recovers then goes into a spin in opposite direction.
[f]Recovered inverted.
[g]Went into an inverted spin.

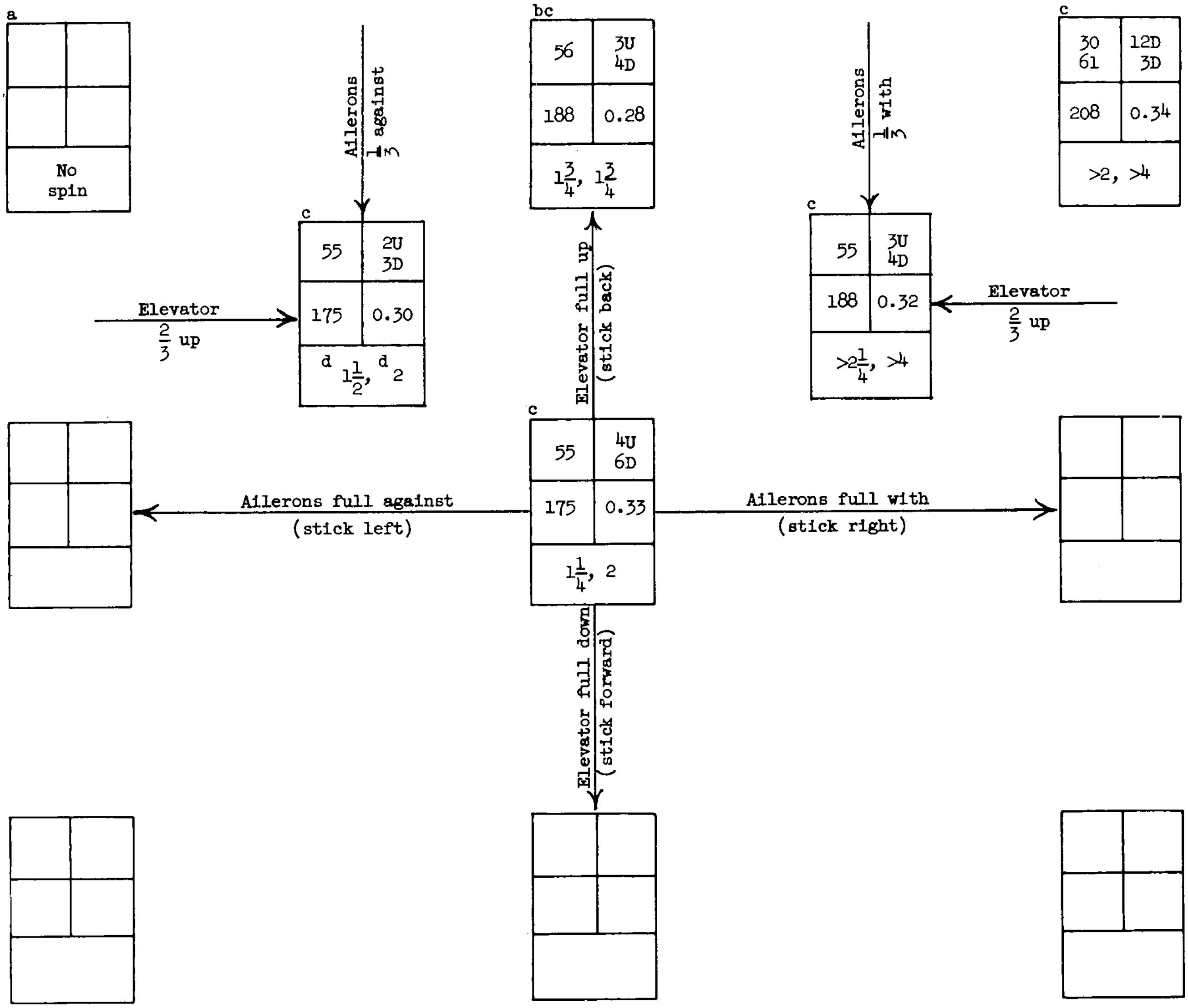
α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 2 .– SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

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

Airplane, Observation	Attitude, Erect	Direction, Right	Loading (see table II) No. 2 Most aft center-of-gravity loading		
Slots, Closed	Flaps, Up		Center-of-gravity position, 30.4 percent $\bar{c}$	Altitude, 18,000 ft	External wing tanks on both wings

Model values converted to full scale U–inner wing up D–inner wing down



[a]Model enters a wide radius glide.
[b]Two conditions possible.
[c]Oscillatory spin; range or average values given.
[d]Recovery by reversal of rudder to $\frac{2}{3}$ against spin.

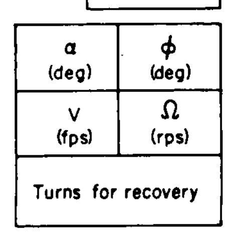


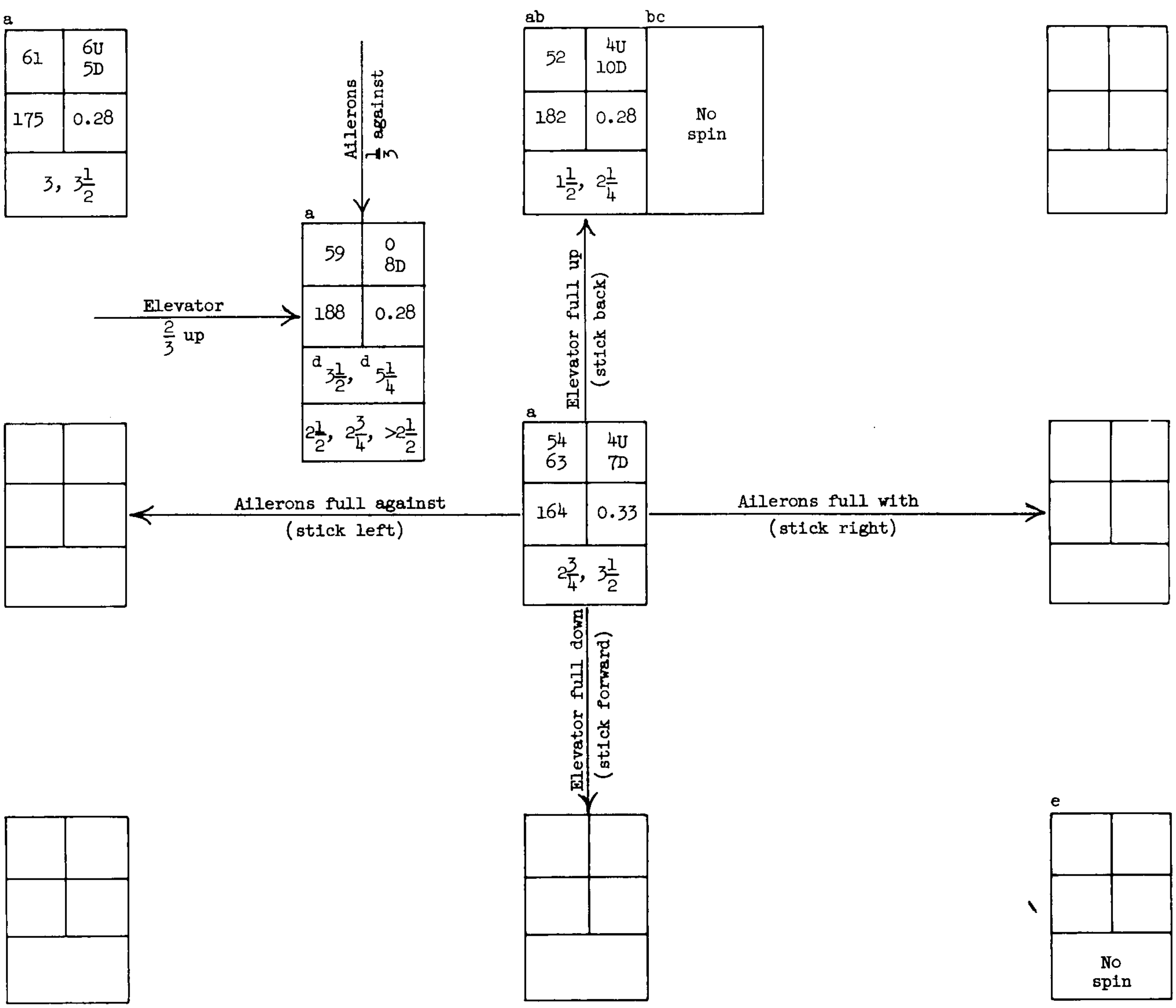
CHART 3 .—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

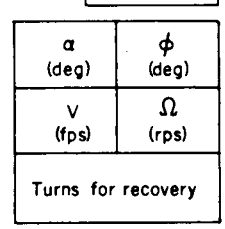
[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

Airplane, Observation	Attitude, Erect	Direction, Right	Loading (see table II) No. 1	Normal loading	
Slats, Open	Flaps, Down		Center-of-gravity position, 25 percent $\bar{c}$	Altitude, 18,000 ft	Landing configuration

Model values converted to full scale

U–inner wing up D–inner wing down





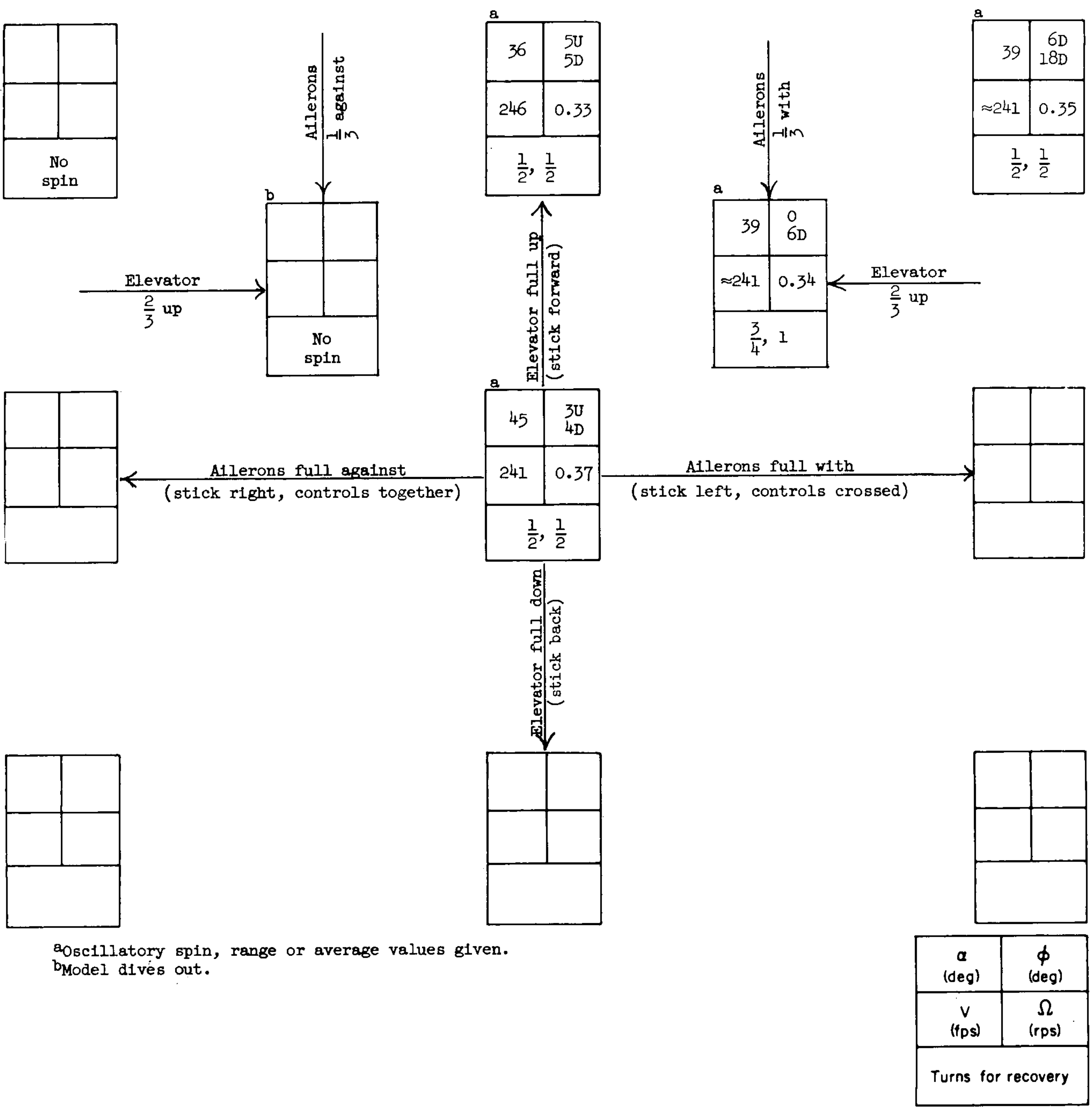
[a]Oscillatory spin; range or average values given.
[b]Two conditions possible.
[c]Goes into glide.
[d]Recovery by reversal of rudder to $\frac{2}{3}$ against spin.
[e]Goes into a vertical roll.

CHART 4 .—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

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

Airplane, Observation	Attitude, Inverted	Direction, To pilot's left	Loading (see table II) No. 1 Normal loading		
Slats, Closed	Flaps, Up		Center-of-gravity position, 25 percent $\bar{c}$	Altitude, 18,000 ft	Clean condition

Model values converted to full scale U–inner wing up D–inner wing down



[a]Oscillatory spin, range or average values given.
[b]Model dives out.

TABLE III.- SPIN-RECOVERY TAIL-PARACHUTE DATA OBTAINED WITH THE $\frac{1}{20}$-SCALE MODEL

OF AN OBSERVATION AIRPLANE

[Control settings for spin: rudder 25° with; elevator 17° up; ailerons 8° against. Recovery attempted by opening tail parachute alone or parachute and rudder movement as shown; right erect spins, clean condition except as noted. C_D of parachutes approximately 0.65; parachute shroud-line length 1.35 × parachute diameter.]

Loading number	Parachute diameter (full scale), ft	Towline length (full scale), ft	Control for recovery, deg	Turns for recovery
			Rudder	
1	12.5	21.7	----	$>2, >2\frac{1}{4}, >2\frac{1}{2}, >3, >3$
1	13.3	21.7	----	$1\frac{1}{4}, 1\frac{1}{2}, 2, >2\frac{1}{4}, >3, >3$
1	14.2	21.7	----	$1, 1, >1\frac{1}{2}, >1\frac{1}{2}, >2, >2$
1	14.2	21.7	0	$\frac{3}{4}, \frac{3}{4}, \frac{3}{4}, \frac{1}{2}, 1$
1	12.5	21.7	0	$\frac{1}{2}, \frac{3}{4}, \frac{3}{4}, \frac{3}{4}$
1	12.5	21.7	Free	$1, 1\frac{1}{2}$
1	10.0	21.7	0	$1\frac{1}{2}, 1\frac{1}{2}, 1\frac{1}{2}, 1\frac{3}{4}, 1\frac{3}{4}$
1	8.3	21.7	0	$1\frac{3}{4}, 1\frac{3}{4}, 2, >2$
1	13.3	43.3	----	$1\frac{1}{2}, 1\frac{1}{2}, 1\frac{1}{2}$
1	10.0	43.3	0	$2, >2$
2	12.5	21.7	----	$>2\frac{1}{2}, >2\frac{1}{4}, 3, >2\frac{3}{4}$
2	12.5	21.7	Free	$1, 1, 1\frac{1}{4}$
2	12.5	21.7	0	$1, 1, \frac{3}{4}, 1$
[a]2	12.5	21.7	0	$\frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}$
[b]2	12.5	21.7	0	$\frac{3}{4}, \frac{3}{4}, \frac{3}{4}, 1, 1, 1\frac{1}{2}$
[c]1	12.5	21.7	----	$2\frac{1}{2}, >2\frac{1}{2}$
[c]1	12.5	21.7	0	$1\frac{1}{2}, 1\frac{3}{4}, 1\frac{3}{4}$

[a]Full external wing tank on right wing only.
[b]Full external wing tank on left wing only.
[c]Flaps down.

For any control settings where spins were obtained, rapid recoveries were obtained by reversing the rudder to full against the spin. The recommended technique for recovery from inverted spins for all loading conditions is to reverse the rudder to full against the spin and to neutralize the lateral and longitudinal controls.

Spin-Recovery Parachute Tests

The results of tests made to determine the size of the tail parachute required to give satisfactory recoveries for the airplane during emergencies in spin demonstrations are presented in table III. The results indicate that a parachute larger than 14 feet in diameter (laid out flat and $C_D = 0.65$ based on laid-out-flat diameter) would be required based on the normal test procedure (recovery by parachute action alone with pro-spin controls set on the model). However, because of structural limitations of the fuselage at the tail section of the airplane a parachute larger than 12.5 feet in diameter ($C_D = 0.65$) cannot be used. Therefore, for this airplane the tests were made by using rudder movement to neutral simultaneously with the parachute deployment for recoveries. The results indicate that satisfactory recoveries could be obtained with a flat-type stable parachute of 12.5-foot diameter (laid out flat) with a drag coefficient of 0.65 (based on laid-out-flat area) simultaneously with movement of the rudder to neutral. A towline length of 21.7 feet was used. The results indicate that this size of parachute and towline length will be sufficient for satisfactory recoveries for the normal loading (clean condition or flaps deflected), the loading with full external wing tanks on, and for the condition when one full tank is on either the right or left wing. If a parachute with a different drag coefficient is used, a corresponding adjustment will be required in parachute size.

Recommended Recovery Technique

On the basis of the results obtained with the model, the following recovery technique is recommended:

For erect spins in the normal loading, the rudder should be moved to full against the spin, ailerons to with the spin, and forward movement of the stick to neutral about one-half turn later. For the loading with empty wing tanks on or with one empty tank on either the outboard or inboard wing, or when the radar store is installed, rudder should be moved to full against the spin, ailerons to with the spin, followed about one-half turn later by forward stick movement to neutral. The optimum recovery control technique for the full-wing-tank loading or for loading with one tank on the wing either outboard or inboard of the spin axis is full rudder reversal followed by brisk stick movement to full forward. However, if recovery does not appear imminent for any loading condition in which external wing tanks (either empty or full) are installed, the tanks should be jettisoned and recovery technique for the normal loading should be used.

For inverted spins for all loading conditions, the rudder should be reversed to full against the spin and the lateral and longitudinal controls should be neutralized.

For the spins in landing configuration it is recommended that the flaps be raised and slats closed, then the recovery technique for the normal loading should be used.

CONCLUSIONS

Based on the results of tests of a 1/20-scale model of an unswept-wing twin-engine observation airplane, the following conclusions regarding the spin and recovery characteristics of the airplane at an altitude of 18,000 feet are made:

1. Recoveries from erect spins for the normal loading will be satisfactory by rudder reversal to full against the spin, aileron movement to with the spin, and forward movement of the stick to neutral about one-half turn later. When external stores are carried, for example, a radar store or empty wing tanks, or an empty tank on either the wing outboard or inboard of the spin axis, satisfactory recoveries can be obtained by using the same recovery technique as for the normal loading.

2. Recoveries from erect spins for the rearward center-of-gravity loading (external wing tanks full) or with a full tank on the inboard wing, will be slow to unsatisfactory with rudder reversal to full against the spin followed by brisk forward stick movement. With a full tank on the wing outboard of the spin axis, the recoveries will be satisfactory.

3. If a spin is inadvertently entered in the landing configuration, the flaps, slats, and landing gear should be retracted and recovery should be attempted immediately by using the procedure specified for the normal loading.

4. Satisfactory recoveries will be obtained from any inverted spin by rudder reversal to full against the spin followed by neutralization of the longitudinal and lateral controls.

5. A 12.5-foot-diameter (laid out flat) tail parachute with a towline 21.7 feet long and a drag coefficient of 0.65 based on laid-out-flat diameter will be satisfactory for emergency recoveries from erect and inverted demonstration spins when it is used simultaneously with movement of the rudder to neutral.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 11, 1962.

APPENDIX

TEST METHODS AND PRECISION

Model Testing Technique

The operation of the Langley 20-foot free-spinning tunnel is generally similar to that described in reference 1 for the Langley 15-foot free-spinning tunnel except that the model-launching technique is different. With the controls set in the desired position, a model is launched by hand with rotation into the vertically rising airstream. After a number of turns in the established spin, a recovery attempt is made by moving one or more controls by means of a remote-control mechanism. After recovery, the model dives into a safety net. The tests are photographed with a motion-picture camera. The spin data obtained from these tests are then converted to corresponding full-scale values by methods described in reference 1.

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a model for the normal control configuration for spinning (elevator full up, lateral controls neutral, and rudder full with the spin) and for various other lateral control and elevator 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 ailerons full with the spin. The particular control manipulation required for recovery is generally dependent on the mass and dimensional characteristics of the model (refs. 2 and 3). Tests are also performed to evaluate the possible adverse effects on recovery of small deviations from the normal control configuration for spinning. 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 the 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 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 dimensional 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 the criterion spin in any of the manners previously described is accomplished within $2\frac{1}{4}$ turns. This value has been selected on the basis of full-scale-airplane spin-recovery data that are available for comparison with corresponding model test results.

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 feet per second, 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. When a model recovers without control movement (rudder held with the spin), the results are recorded as "no spin."

For spin-recovery parachute tests, the minimum-size tail parachute required to effect recovery within $2\frac{1}{4}$ turns from the criterion spin is determined. The parachute is opened for the recovery attempts by actuating the remote-control mechanism, and the rudder is usually held with the spin so that recovery is due to the parachute action alone. The parachute towline is generally attached to the bottom rear of the fuselage. The folded spin-recovery parachute is placed on the model in such a position that it does not seriously influence the established spin. A rubber band holds the packed parachute to the model; when the band is released the parachute canopy is blown free of the model. On full-scale parachute installations it is desirable to mount the parachute pack within the airplane structure, if possible, and it is recommended that a mechanism be employed for positive ejection of the parachute.

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	$\pm\frac{1}{4}$
Turns for recovery obtained visually	$\pm\frac{1}{2}$

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.

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 with an accuracy of ±1°.

Variations in Model Mass Characteristics

Because it is impracticable 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 airplane values within the following limits:

I_X, percent	2 low to 18 high
I_Y, percent	4 high to 25 high
I_Z, percent	0 to 19 high

Comparison of Model and Airplane Results

The comparison of model results and full-scale results in reference 4 indicated that the free-spinning-tunnel tests of models, properly interpreted, can give good indications of the probable spin and recovery characteristics of corresponding airplanes and have proven to be extremely reliable as a means of determining optimum-control technique for best recovery from spins.

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