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FREE-SPINNING-TUNNEL INVESTIGATION OF A 1/20-SCALE MODEL OF AN UNSWEPT-WING JET-PROPELLED TRAINER AIRPLANE

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SUMMARY

An investigation has been made in the Langley 20-foot free-spinning tunnel to determine the erect and inverted spin and recovery characteristics of a 1/20-scale dynamic model of a jet-propelled trainer airplane.

The model results indicate that the optimum technique for recovery from erect spins of the airplane will be dependent on the distribution of the disposable load. The recommended recovery procedure for spins encountered at the flight design gross weight is simultaneous rudder reversal to against the spin and aileron movement to with the spin. With full wingtip tanks plus rocket installation and full internal fuel load, rudder reversal should be followed by a downward movement of the elevator. For the flight design gross weight plus partially full wingtip tanks, recovery should be attempted by simultaneous rudder reversal to against the spin, movement of ailerons to with the spin, and ejection of the wingtip tanks.

The optimum recovery technique for airplane-inverted spins is rudder reversal to against the spin with the stick maintained longitudinally and laterally neutral.

INTRODUCTION

An investigation has been made in the Langley 20-foot free-spinning tunnel to determine the spin and spin-recovery characteristics of a 1/20-scale dynamic model of an unswept-wing, jet-propelled, two-place tandem trainer airplane.

The erect spin and recovery characteristics of the model were determined for the flight design gross weight; for a loading condition with full wingtip tanks, rocket installation, and full internal fuel load; and for the flight design gross weight plus partially full wingtip tanks. The inverted-spin investigation was made for the flight design gross weight, both with and without partially full wingtip tanks.

SYMBOLS

b	wing span, ft
S	wing area, sq ft
$\bar{c}$	mean aerodynamic chord, ft
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below line)
m	mass of airplane, slugs
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
ρ	air density, slug/cu ft
μ	relative density factor of airplane, $m/\rho Sb$
α	angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg
ϕ	angle between span axis and horizontal, deg
V	full-scale true rate of descent, fps
Ω	full-scale angular velocity about spin axis, rps

MODEL AND TESTING TECHNIQUES

The 1/20-scale dynamic model of a jet-propelled trainer airplane was used for the investigation. The model was constructed primarily of molded plastic-impregnated Fiberglas. The dimensional characteristics of the airplane are presented in table I. A three-view drawing of the model as tested is shown in figure 1. A modified rudder configuration is shown in figure 2. Photographs of the model are shown in figures 3 and 4.

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The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 35,000 feet (ρ = 0.000736 slug/cu ft). The mass characteristics for the loadings of the airplane and for the loadings tested on the model are presented in table II. A remote-control mechanism was installed in the model to actuate the controls and sufficient torque was applied to the controls to reverse them fully and rapidly for the recovery attempts. Controls were set with an accuracy of $\pm 1^{\circ}$.

The following normal maximum control deflections (measured perpendicular to the control hinge lines) were used during the test program:

Rudder deflection, deg:	
Right	25
Left	25
Elevator deflection, deg:	
Up	27
Down	15
Aileron deflection, deg:	
Up	12
Down	13

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a model for the normal spinning-control configuration (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 deflection of ailerons to full with the spin. The particular control manipulation required for recovery is generally dependent on the mass and dimensional characteristics of the model (ref. 1). 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 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 simultaneously reversing the rudder to two-thirds against the spin and moving the elevator to either neutral or two-thirds down, or by simultaneously reversing the rudder to two-thirds against the spin and moving the stick to two-thirds with the spin. The control configuration and manipulation used 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.

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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 spin-recovery data of full-scale airplanes that are available for comparison with corresponding model test results.

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

Model spin-recovery information as presented in the charts includes the following notation: 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 are moved to the time that the model strikes the net, as >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."

RESULTS AND DISCUSSION

The results of the model tests are presented in charts 1 to 5. Inasmuch as the results to the right and left were generally similar, the data are arbitrarily presented in terms of right spins.

During the test program, the rudder was changed from a single surface to a divided configuration, with movable portions above and below the horizontal tail, and the inboard elevator cutouts were eliminated (fig. 2). Brief tests were made with a fence on the vertical tail (fig. 1). No significant influence on the spin and recovery characteristics of the model was observed due to either modification.

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Erect Spins

Because of variations in disposable load, the possible mass distribution of the airplane can vary from a condition in which the loading is predominantly along the wings to one in which the airplane is loaded predominantly along the fuselage. (Wing-heavy and fuselage-heavy loadings based on full-scale inertia calculations and a loading for which I_X and I_Y were similar were investigated.) As discussed in reference 1, the optimum recovery technique for an airplane is dependent on the arrangement of the loading; therefore, if the distribution varies widely, alternate techniques may be required. The techniques determined for the spin test model are discussed under the various loading conditions tested.

<u>Flight design gross weight</u>.- The results of tests conducted with the model ballasted for the flight design gross weight $\left(\frac{I_X - I_Y}{mb^2} = -187 \times 10^{-4}\right.$, loading 1 in table II$\left.\right)$ are presented in chart 1. As indicated in the chart, maintaining ailerons against the spin tends to retard recovery, and maintaining elevator full up tends to promote recovery. Based on the results obtained for the criterion spin, the optimum recovery technique recommended for the airplane at the flight design gross weight is simultaneous rudder reversal to full against the spin and movement of ailerons to full with the spin (stick right in a right spin). The elevator should be maintained full up until recovery appears imminent.

<u>Full wingtip tanks plus rocket installation and full internal fuel load</u>.- The results of tests conducted with the model ballasted with full wingtip tanks plus rocket installation and full internal fuel load

$\left(\frac{I_X - I_Y}{mb^2} = 182 \times 10^{-4}\text{, loading 4 in table II}\right)$ are presented in chart 2. The model results indicate that satisfactory recoveries are obtainable by rudder reversal and downward movement of the elevator. The recommended airplane recovery procedure is rudder reversal to full against the spin followed approximately one-half turn later by forward movement of the stick. Aileron effects appear to be minor, but it is advisable to avoid aileron deflection with the spin for this loading while attempting recovery.

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Flight design gross weight plus partially full wingtip tanks.- Model tests (not presented in chart form) for the flight design gross weight plus partially full wingtip tanks $\left(\frac{I_X - I_Y}{mb^2} = -18 \times 10^{-4}\text{, loading 7 in table II}\right)$ indicated that satisfactory recoveries could not be obtained either by rudder reversal alone or by rudder reversal accompanied by movement of elevator to full down. The use of strakes as an aid to recovery was also investigated but recoveries attempted by rudder reversal with various strakes (ref. 1) mounted on the nose were unsatisfactory.

The results presented in chart 3 indicate that satisfactory recoveries from inadvertent spins can be obtained by simultaneous rudder reversal to against the spin, movement of ailerons to with the spin, and ejection of the wingtip tanks. The elevator should be maintained full up until recovery appears imminent. Intentional spinning in this condition should be avoided.

Inverted Spins

The order used for presenting the data for the inverted spins is different from that used for erect spins. For inverted spins, the "controls crossed" condition for the developed spin (right rudder pedal forward and stick to the pilot's left for a spin to the pilot's right) is presented to the right of the chart and the "stick back" condition is presented at the bottom of the chart. When the controls are crossed in the developed spin, the lateral controls aid the rolling motion; when the controls are together, the lateral controls oppose the rolling motion. The angle ϕ and the longitudinal control position in the chart (and text) are given as up or down relative to the ground.

The results of model inverted spin tests for the flight design gross weight (loading 1 in table II) are presented in chart 4 and for the flight design gross weight plus partially full wingtip tanks (loading 7 in table II) in chart 5. The model spun steeply in the inverted attitude and recovered rapidly. Inverted spins encountered by the airplane should be readily terminated by full rudder reversal to against the spin with the stick longitudinally and laterally neutral.

SUMMARY OF RESULTS

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From a free-spinning tunnel investigation of a 1/20-scale dynamic model of an unswept-wing jet-propelled trainer airplane at a simulated test altitude of 35,000 feet, the following results are considered applicable to the spin and recovery characteristics of the corresponding airplane:

1. The optimum technique for satisfactory recovery from erect spins will vary according to the airplane mass distribution. For the flight design gross weight, recovery should be attempted by simultaneous rudder reversal to against the spin and movement of ailerons to with the spin; with full wingtip tanks plus rocket installation and full internal fuel load, rudder reversal to against the spin should be followed by downward movement of the elevator; for the flight design gross weight plus partially full wingtip tanks, the recommended technique is simultaneous rudder reversal to against the spin, movement of ailerons to with the spin, and ejection of the wingtip tanks.

2. Satisfactory recovery from airplane inverted spins should be obtained by rudder reversal to against the spin with the longitudinal and lateral controls maintained at neutral.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 23, 1959.

REFERENCE

1. Neihouse, Anshal I., Klinar, Walter J., and Scher, Stanley H.: Status of Spin Research for Recent Airplane Designs. NACA RM L57F12, 1957.

TABLE I.- DIMENSIONAL CHARACTERISTICS OF AIRPLANE

REPRESENTED BY THE 1/20-SCALE MODEL

Overall length, ft	38.27
Wing:	
Span, ft	36
Area, sq ft	255
Root chord, in.	114.27
Tip chord, in.	56.66
Mean aerodynamic chord, in.	88.88
Leading edge of $\bar{c}$ rearward of leading edge of root chord, in.	10.16
Aspect ratio	5.0
Taper ratio	0.50
Dihedral, deg	3
Sweepback of 40 percent chord, deg	0
Incidence:	
Root, deg	2
Tip, deg	-1
Airfoil section (a = 0.8) modified	NACA 64_1A212
Ailerons:	
Total area, rearward of hinge line, sq ft	19.00
Span, each, percent of b/2	37.36
Horizontal tail:	
Span, ft	17.87
Total area, sq ft	70
Root chord, in.	63.11
Tip chord, in.	31.33
Sweepback of quarter chord, deg	15.00
Total elevator area, rearward of hinge line, sq ft	17.83
Dihedral, deg	0
Airfoil section	NACA 65_1A012
Vertical tail:	
Span, to equivalent tip, ft	7.11
Area, sq ft	38.11
Root chord, in.	78.14
Tip chord, in.	34.52
Sweepback of quarter chord, deg	30.00
Rudder area, rearward of hinge line, sq ft	10.65
Airfoil section	NACA 63_1A012

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

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

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	35,000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane											
1 - Flight design gross weight, gear up	9,507	0.234	0.030	13.51	43.64	4,814	12,135	15,228	-191×10^{-4}	-82×10^{-4}	273×10^{-4}
2 - Basic catapult design, gross weight, tip tanks installed and full, gear up	10,961	.237	.043	15.57	50.30	20,057	12,424	30,710	173	-415	242
3 - Basic design gross weight, with rocket packages, gear up	10,014	.212	.023	14.25	46.01	6,174	12,982	17,392	-169	-109	278
4 - Wingtip tanks and rocket installation, full fuel, gear up	11,486	.218	.036	16.35	52.81	21,514	13,315	33,065	177	-427	250
5 - Wingtip tanks and rocket installation, internal fuel only, gear up	10,184	.215	.025	14.48	46.75	7,952	13,025	19,211	-126	-151	277
6 - Design landing gross weight (clean), 1/2 internal fuel, gear up	8,269	.216	.000	11.77	38.02	4,697	11,866	15,048	-215	-97	312
Model											
1 - Flight design gross weight	9,515	0.234	0.012	13.54	43.74	4,587	11,767	14,181	-187×10^{-4}	-64×10^{-4}	251×10^{-4}
4 - Wingtip tanks and rocket installation and full fuel	11,485	.224	.021	16.33	52.74	21,846	13,464	32,440	182	-411	229
7 - Flight design gross weight plus partially full wing-tip tanks	10,420	.245	.023	14.[illegible]3	47.89	11,512	12,262	21,759	-18	-227	245

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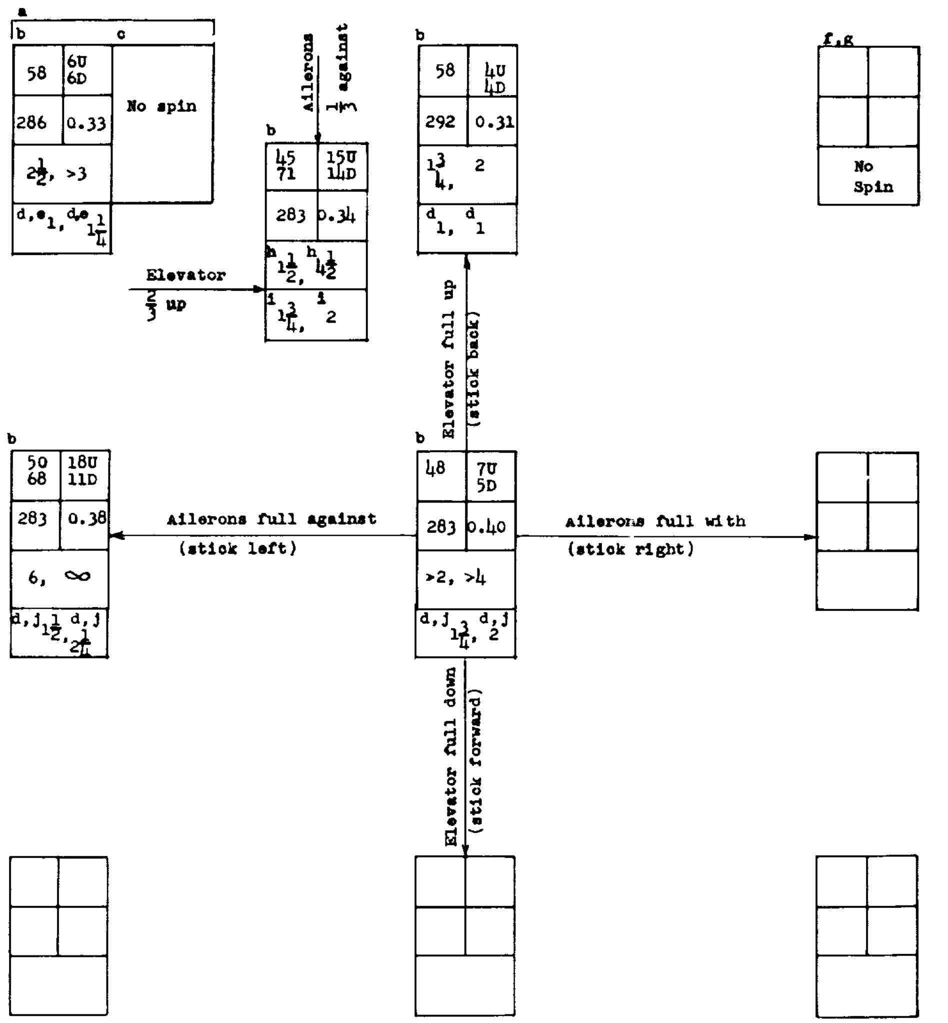
CHART 1. - SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

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

Trainer	Attitude Erect	Divided Rudder	Loading 1 in table II Flight design gross weight	Wing tip tanks: Off Rocket pods: Off
Direction Right	Altitude 35,000 ft		Center-of-gravity position: 23.4 percent $\bar{c}$	



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

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

[a]Two conditions possible
[b]Oscillatory spin, range or average values given
[c]Model entered a glide
[d]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full with the spin
[e]Visual estimate
[f]Model entered a dive
[g]Visual observation
[h]Recovery attempted by reversing rudder from full with to 2/3 against the spin
[i]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 with the spin
[j]Recovered in an aileron roll

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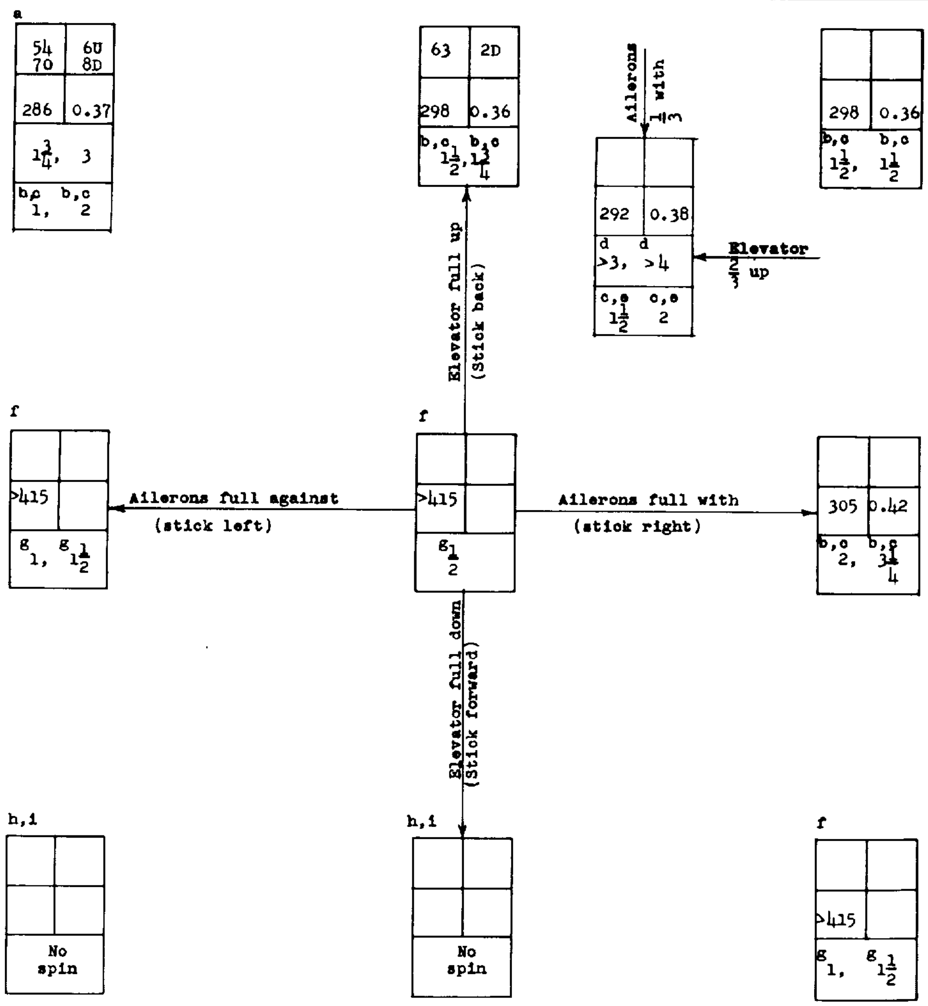
CHART 2.-SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

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

Trainer	Attitude Erect	Single piece rudder	Loading 4 in table II Wing tip tanks plus rocket installation, full fuel	Wing tip tanks: On
Direction Right	Altitude 35,000 ft		Center-of-gravity position: 22.4 percent $\bar{c}$	Rocket pods: On



[a]Oscillatory spin, range or average values given
[b]Recovery attempted by simultaneous full rudder reversal and movement of elevator to full down
[c]Recovered in an inverted dive
[d]Recovery attempted by reversing rudder from full with to 2/3 against the spin
[e]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of elevator to 2/3 down
[f]Steep spin; recovery attempted before final attitude attained
[g]Visual estimate
[h]Model entered an inverted dive
[i]Visual observation

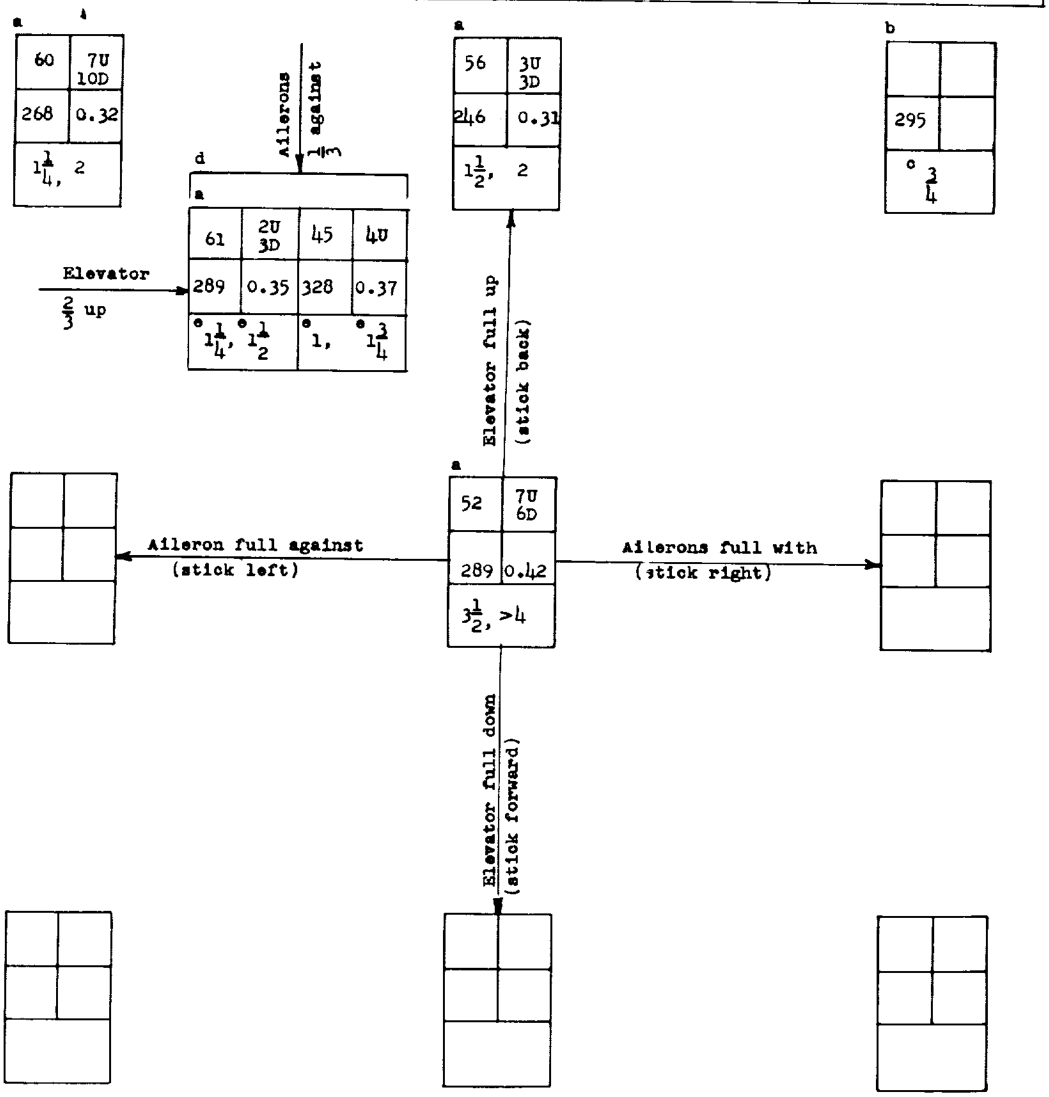
Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

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

CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by simultaneous reversal of rudder to full against the spin, movement of ailerons to full with the spin, and ejection of wing tip tanks unless otherwise indicated (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

Trainer	Attitude Erect	Divided Rudder	Loading 7 in table II-Flight design gross weight plus partially full wing tip tanks	Rocket pods: Off Wing tip tanks: On
Direction Right	Altitude 35,000 ft		Center-of-gravity position: 24.5 percent $\bar{c}$	



[a]Oscillatory spin, range or average values given

[b]Very oscillatory and wandering spin

[c]Visual estimate

[d]Two conditions possible

[e]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin, movement of ailerons to 2/3 with the spin, and ejection of wing tip tanks

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

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

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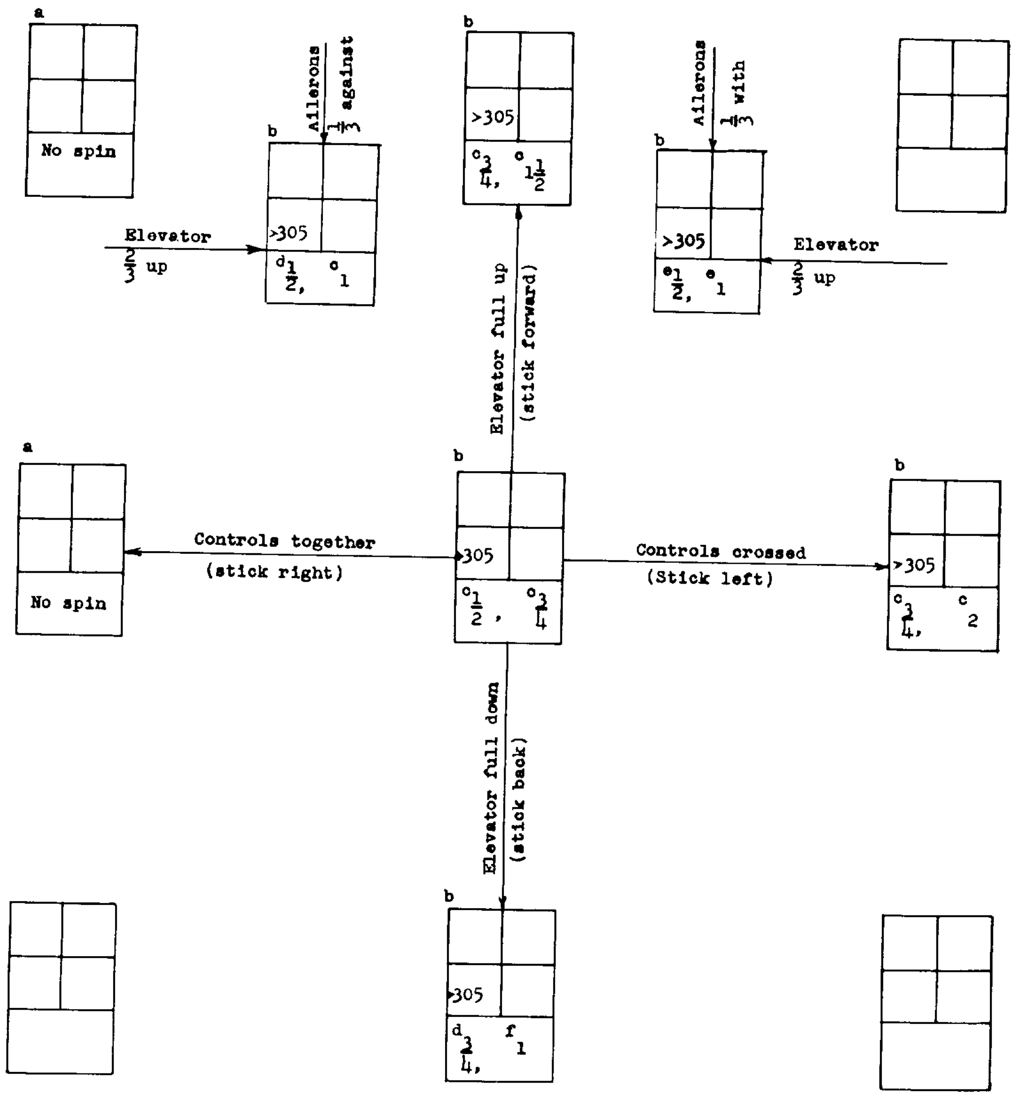
CHART 4.-SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

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

Trainer	Attitude Inverted	Single piece rudder	Loading 1 in table II Flight design gross weight	Wing tip tanks: Off
Direction To pilot's right	Altitude 35,000 ft		Center-of-gravity position: 23.4 percent	Rocket pods: Off



[a]Model entered an erect dive
[b]Steep spin; recovery attempted before final attitude attained
[c]Recovered in an erect dive
[d]Visual estimate
[e]Recovered in an inverted dive
[f]Recovered in a vertical dive

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

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

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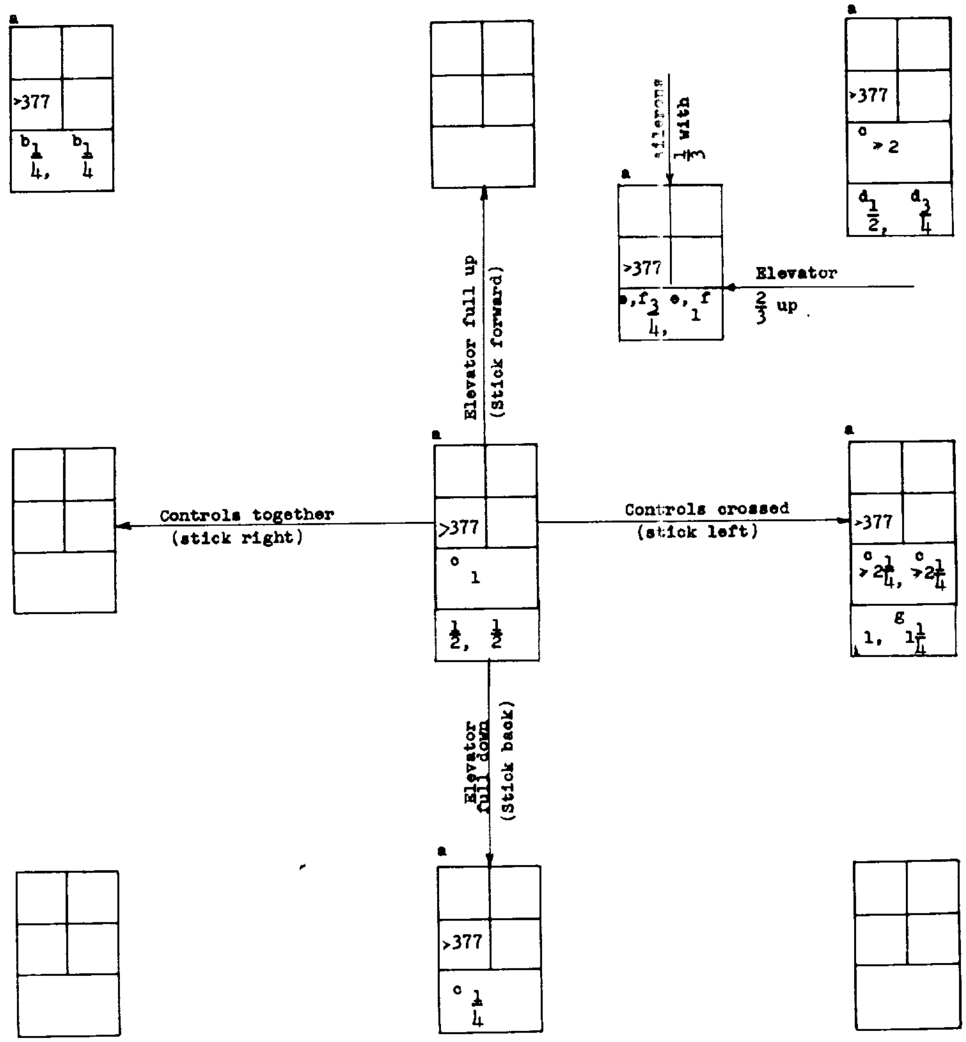
CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

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

Trainer	Attitude Inverted	Single piece rudder	Loading 7 in table II-Flight design gross weight plus partially full wing tip tanks	Wing tip tanks: On
Direction To pilot's right	Altitude 35,000 ft		Center-of-gravity position: 24.5 percent $\bar{c}$	Rocket pods: Off



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

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

[a]Steep spin, recovery attempted before final attitude attained
[b]Recovered in a short glide followed by a turn in the opposite direction
[c]Recovery attempted by rudder neutralization
[d]Recovered in an aileron roll
[e]Recovery attempted by reversing rudder from full with to 2/3 against the spin
[f]Recovered in an inverted dive
[g]Recovered in a short glide and rolled inverted

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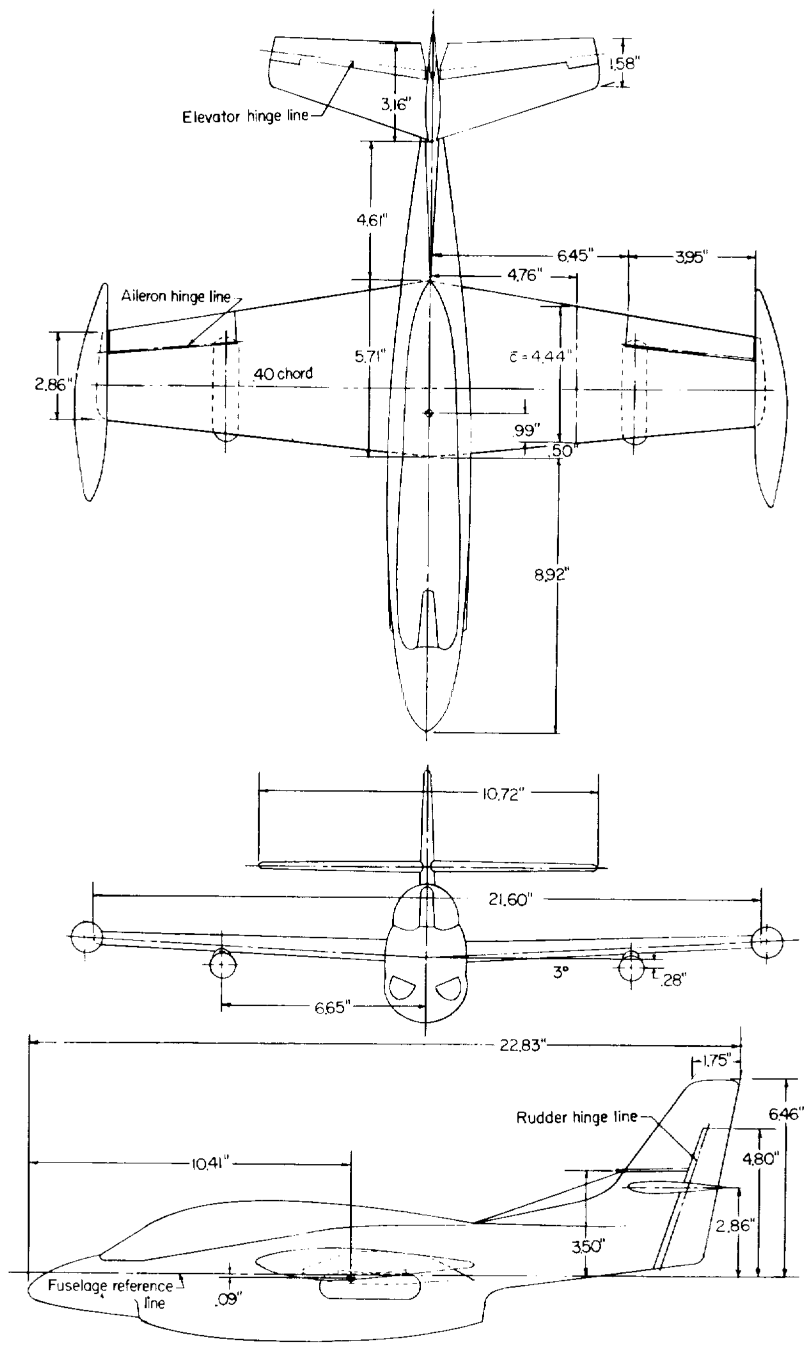

Figure 1.- Three-view drawing of the 1/20-scale model of the trainer airplane. Center-of-gravity position indicated is for the loading condition with wingtip tanks and rocket installation and full fuel.

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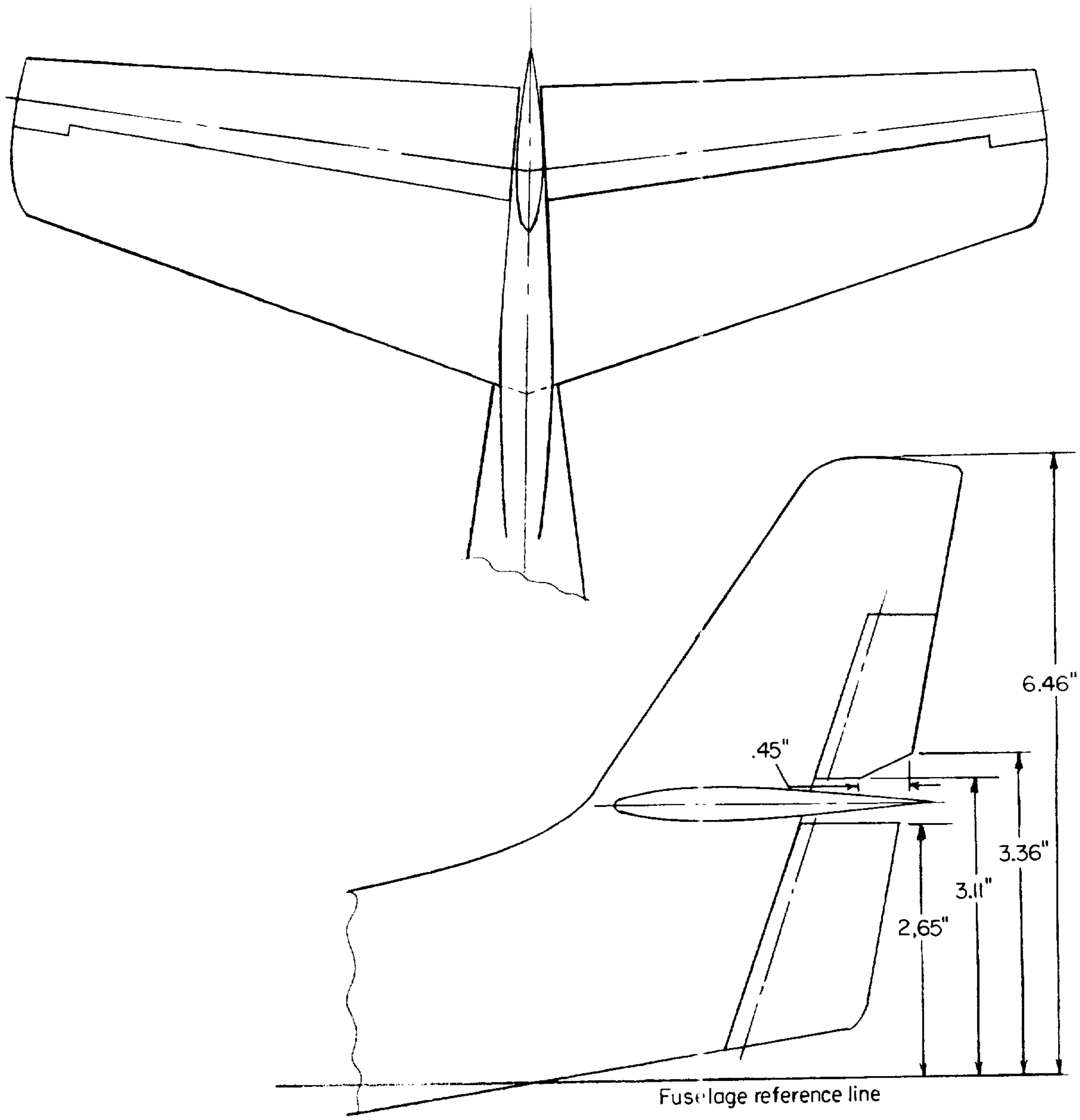

Figure 2.- Divided-rudder configuration tested on model.

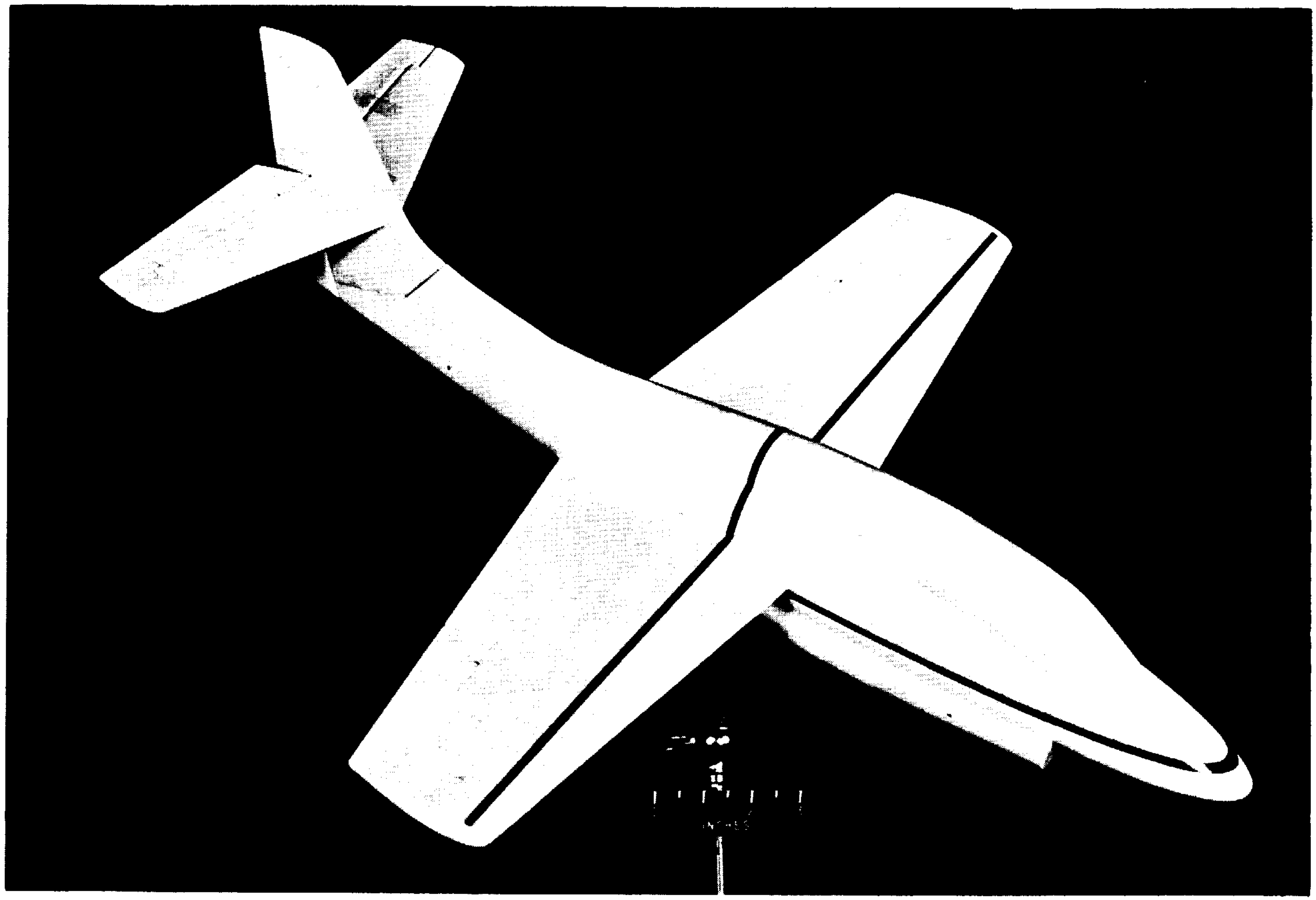

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Figure 3.- Photograph of the 1/20-scale spin test model in the clean condition.

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Figure 4.- Photograph of the 1/20-scale spin test model with wingtip tanks and rocket pods.

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