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SPIN-TUNNEL INVESTIGATION OF A 1/20-SCALE MODEL OF A MODIFIED STRAIGHT-WING, TWIN-BOOM, COUNTER-INSURGENCY AIRPLANE

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16. Abstract

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SUMMARY

An investigation has been made in the Langley spin tunnel to determine the spin and recovery characteristics of a 1/20-scale dynamic model of a modified straight-wing, twin-boom, counter-insurgency airplane. Tests were made for the normal loading with the center of gravity at 23 percent mean aerodynamic chord and for a rearward center-of-gravity position of 30 percent mean aerodynamic chord. The use of rockets as an emergency recovery device was also investigated.

The test results indicate that the airplane will spin in the erect attitude for all loading conditions and will spin inverted only for ailerons-with control settings. The optimum control technique for recovery from all spins is movement of the rudder to against the spin followed about one-half turn later by neutralization of the longitudinal and lateral controls. Satisfactory emergency recoveries from spins can be obtained by the use of rockets that produce an antispin yawing moment (about the Z body axis) of at least 27 600 ft-lb (37 421 m-N) for at least 4.5 seconds.

INTRODUCTION

The subject investigation was made to determine the spin and recovery characteristics of a 1/20-scale model of a straight-wing, twin-boom, counter-insurgency airplane. The airplane is a modification of the airplane previously tested in reference 1. Therefore, the present investigation was also conducted to determine if the aircraft configuration and mass characteristic changes between the airplane previously tested and the present airplane could cause any appreciable change in the spin and recovery characteristics.

SYMBOLS

b wing span, feet (meters)

$\bar{c}$ mean aerodynamic chord, feet (meters)

I_X, I_Y, I_Z moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2 (kilogram-meters^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 (kilograms)

S wing area, feet^2 (meters^2)

V full-scale true rate of descent, feet/second (meters/second)

x distance of center of gravity rearward of leading edge of mean aerodynamic chord, feet (meters)

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

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

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

ρ air density, slugs/foot^3 (kilograms/meter^3)

ϕ angle between span axis and horizontal, degrees

Ω full-scale angular velocity about spin axis, revolutions/second

TESTS

The tests were run in the Langley spin tunnel, which is described in reference 2. The test technique is described in detail in reference 2, and a brief summary of the technique is given in the appendix of the present report for the convenience of the reader. The appendix also indicates the precision of measurement of the characteristics of the spin.

The erect and inverted spin and recovery characteristics were determined for center-of-gravity locations of 23 percent and 30 percent of the mean aerodynamic chord. The effects of upper-surface spoilers and both inboard and outboard ailerons were investigated. Tests were also conducted with small rockets mounted on the wing tips to determine the yawing moment required for an emergency spin recovery.

MODEL

A 1/20-scale model of the airplane was built and prepared for testing by the Langley Research Center. A three-view drawing of the model showing the comparison of the present modified design with the original design is shown in figure 1, and photographs of the model in the clean configuration are shown in figure 2. The dimensional characteristics are presented in table I, together with the dimensional characteristics of the original design.

The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 20 000 feet (6096 meters) (ρ = 0.001267 slug/ft^3 or 0.65 kg/m^3). The mass characteristics and inertia parameters for typical loadings possible on the airplane and for the corresponding loading conditions tested on the model are presented in table II.

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 present modified model investigated varied from the true scaled-down values within the following limits:

Weight, percent . . . . 0 to 2.5 high
Center-of-gravity location, percent $\bar{c}$ . . . . 0 to 1 forward
Moments of inertia:
  I_X, percent . . . . 0 to 4 high
  I_Y, percent . . . . 1 high to 2 high
  I_Z, percent . . . . 1 low to 1 high

A remote-control mechanism was installed in the model to actuate the control surfaces and rockets for the recovery attempts. Sufficient torque was exerted on the controls to reverse them fully and rapidly for the recovery attempts. The airplane was equipped with both outboard and inboard ailerons, but when the tests were started only the outboard ailerons were used for normal flight. However, this was later changed so that both the inboard and outboard ailerons were used on the airplane for normal flight. The maximum control deflections (measured perpendicular to the hinge lines) of the airplane used on the model were:

Rudder, deg	25 right, 25 left
Elevator, deg	35 up, 25 down
Ailerons, deg	
Outboard only (first design used)	20 up, 20 down
Outboard plus inboard (design changed)	25 up, 25 down

RESULTS AND DISCUSSION

The results of the model spin tests are presented in charts 1 to 3 and in tables III and IV. The model data are presented in terms of full-scale values for the airplane at an altitude of 20 000 feet (6096 meters). Inasmuch as the results for right and left spins were generally similar, the data are presented arbitrarily in terms of right spins. The model in the clean configuration has the sponsons on. (See fig. 1.) 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 the two propellers of the airplane rotate in opposite directions, there would be virtually no gyroscopic effects on the spinning airplane.

In general, the tests showed that the model had a fairly steep fast-rotating spin with angles of attack of about 20° to 30°. The model appeared to have two spin modes, with the angle of attack of the steeper mode being about 20° and with the angle of attack of the flatter mode being about 30°. The model would alternate from one of these modes to the other so fast that the spin was considered to be oscillatory. For the inverted spins, the tests showed that the model had a fast-rotating spin with angles of attack that oscillated from 25° to 70° and also oscillated in roll about $\pm 25^{\circ}$.

Satisfactory recoveries could be obtained from any of the spins obtained on the model in either the erect or inverted attitudes by use of the optimum control technique, which is reversing the rudder to full against the spin followed about one-half turn later by neutralizing the lateral and longitudinal controls to prevent the model from entering a spin in the opposite direction.

Erect Spins

For erect spins, the data in the charts are presented in the following order: Results for elevator up (stick back) at the top of the chart, results for elevator down (stick forward) at the bottom of the chart, results for ailerons with the spin (stick right in a right spin) 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 for the normal loading (loading 1, see table II) with a center-of-gravity location of $0.23\bar{c}$ are presented in chart 1. These tests were made by using only the outboard ailerons with a $\pm 20^{\circ}$ deflection. The results indicate that the spins are fast and steep. For the normal spin control settings, elevator full up and ailerons neutral, the period of the spin was about 2 seconds per turn at an angle of attack of approximately 25°. This spin condition was about the same for all spins obtained for all control settings investigated. When the controls were set with elevators and ailerons neutral, both a spin and a no spin were obtained, with the no spin being the predominant condition. For the no-spin condition, the model would go into a dive while the pro-spin control settings were maintained. When the controls were set with elevators neutral and the ailerons full against, the model would not spin but would go into a dive. The data presented indicate that for all control combinations investigated, satisfactory recoveries were obtained by reversal of the rudder to full against the spin. The recoveries were rapid in all tests and the post-recovery motion was either a dive or a glide. The gliding motion was usually the result of the elevator being up.

Effect of varying center-of-gravity location.- The results of the erect-spin tests with the rearward center-of-gravity location ($0.30\bar{c}$, loading 8, see table II) for the normal loading are presented in chart 2. These tests were made by using both the outboard and inboard ailerons, with a $\pm 25^{\circ}$ deflection. These results show that generally the spins obtained were similar to those for the normal-loading center-of-gravity location ($0.23\bar{c}$) in chart 1, but the spins were somewhat slower and not quite as steep. For the normal spin control settings, elevator full up and ailerons neutral, the period of the spin was about 2.5 seconds per turn at an angle of attack of approximately 30°. When the controls were set with elevators neutral and the ailerons full against, the model would spin; whereas, with the normal-loading center-of-gravity location of $0.23\bar{c}$, it did not. However, for all spins obtained for all control combinations investigated, satisfactory recoveries were obtained by reversal of the rudder to full against the spin. The recoveries were about the same as they were for the forward center-of-gravity location of $0.23\bar{c}$.

Effect of upper-surface spoilers and inboard and outboard ailerons with increased aileron deflections.- The airplane investigated had inboard and outboard ailerons and upper-surface spoilers for roll control. In normal flight the outboard ailerons with $\pm 20^{\circ}$ deflection and spoilers were originally used. After most of the model test program was completed, the airplane roll-control system was changed so that both the inboard and outboard aileron with $\pm 25^{\circ}$ deflections and spoilers were used. Brief tests were then made on the model to evaluate this change by using both the inboard and outboard ailerons with the increased deflection. The effect of the spoilers was also evaluated. These tests were made for the normal loading with the center-of-gravity location of $0.23\bar{c}$. The results of these tests are presented in table III.

The results indicate that when both inboard and outboard ailerons were used and set against the spin the spin rate (2.5 seconds per turn) was a little slower than when using only the outboard ailerons (2 seconds per turn). However, when both the inboard and outboard ailerons were used and set with the spin, the spin rate was faster (1.6 seconds per turn) than when only the outboard ailerons were used (2 seconds per turn). The results also indicated that the spoilers when deflected up had no effect on the spin. Recoveries were satisfactory from all the spins by reversing the rudder to full against the spin.

Inverted Spins

The order used for presenting the data in the charts for inverted spins is different from that used for erect spins. For inverted spins, data for ailerons with the spin (controls crossed – that is, left rudder pedal forward and stick to the pilot's right for a spin with rotation to the pilot's left) are presented on the right side of the chart and data for the ailerons against the spin (controls together – that is, left rudder pedal forward and stick to the pilot's left for a spin to the pilot's left) are presented on the left side of the chart. When the controls are crossed in an inverted spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion. The angle of wing tilt in the chart is given as up (U) or down (D) relative to the ground. The elevator up or down deflection is also given relative to the ground; therefore, the results for elevator up (stick forward) are presented at the top of the chart and those for elevator down (stick back) are presented at the bottom of the chart.

The results of tests to determine the inverted spin and recovery characteristics are presented in chart 3. The tests were made for the normal loading with rearward center of gravity ($0.30\bar{c}$, loading 8, see table II). Tests were also made by using both the inboard and outboard ailerons with a maximum deflection of 25°. The results show that spins were obtained only when the ailerons were full with the spin. The spins were oscillatory with the angle of attack averaging about 40° and the rate of rotation about 2.5 seconds per turn. The model did not spin for any of the other control settings investigated. Recoveries from the spins were satisfactory by reversing the rudder to full against the spin.

Spin-Recovery Rocket Tests

The results of tests to evaluate the use of rockets for emergency recovery from demonstration spins are presented in table IV. The rockets were mounted on the wings at various distances from the fuselage center line to provide the moments indicated in the table. The rocket thrust and the number of seconds that the rocket fired are shown in the table. Airplane and model values under each heading pertaining to the rockets are given for comparison purposes. The design values are presented for the airplane and the model values used for the tests and converted to full-scale values are presented for the model.

In previous investigations on other models to determine the size rocket needed for spin recovery, the direction of the rocket thrust with respect to the principal axes seemed to be important. The maximum inclination of the principal axes to the body axes on this airplane was about 8°. On the original model (ref. 1), tests were made with the rocket thrust set parallel to the body axes and this setting resulted in a small rolling-moment component about the principal longitudinal axis (aileron-against effects). Tests with the rocket thrust set at a 10° angle to the body axes resulted in a pure yawing moment about the principal vertical axis. The results of the tests in reference 1 indicated that the tilt angle of the thrust vector had no appreciable effect on the recovery characteristics for this design. Therefore, the tests on the present modified model were made with the rocket thrust set parallel to the body axes.

Tests were made on the model for the normal loading and center-of-gravity position (loading 1, see table II), the normal loading and rearward center-of-gravity position (loading 8, table II), and for a wing heavy condition where $\frac{I_X - I_Y}{mb^2} = 94 \times 10^{-4}$ (loading 9, table II). The tests were made for the wing heavy condition to simulate a loading that was possible on the original design. (See ref. 1.)

The results of the tests presented in table IV indicate that approximately 27 600 ft-lb (37 421 m-N) of yawing moment for 4.47 seconds (full scale) was adequate for satisfactory recoveries.

It is of importance to point out the significance of some of the unsatisfactory rocket recovery attempts obtained on the original design, as seen in reference 1. In several tests where no recovery was obtained, the total impulse was the same as that used for some of the satisfactory recovery attempts, but the applied yawing moment was less for the no-recovery results. A small yawing moment may be unsatisfactory, therefore, even though it could be applied over a long period of time. In addition, these results have shown that a rocket with a short burning time cannot necessarily be compensated for by increasing the applied yawing moment. In many cases, the unsatisfactory recoveries resulted because the model did not stop rotating by the time the rocket stopped firing. It is necessary, therefore, that the rocket not only provide sufficient yawing moment for recovery, but also provide the moment for as long as the rotation is present.

Recommended Recovery Technique

On the basis of the results obtained in this investigation, the following recovery technique is recommended for the airplane for erect and inverted spins for all loading conditions: Move rudder to full against the spin and then move the elevators and ailerons to neutral about one-half turn later.

Comparison of Model Test Results of the Modified Airplane With Those of Original Airplane (Ref. 1)

As previously mentioned, the dimensional characteristics which show a comparison between the modified and original (ref. 1) straight-wing, twin-boom, counter-insurgency airplanes are shown in table I. A three-view drawing of the model showing the modified and the original design is shown in figure 1. The results of the spin tests of the original design are presented in reference 1. Comparing the airplane mass characteristics of the original design (ref. 1, table II) with the modified design (table II), it can be seen that the weight for the modified model is about 20 percent higher, the center of gravity for normal loading conditions is farther forward, and the moment of inertias have changed so that the inertia yawing-moment parameter $\frac{I_X - I_Y}{mb^2}$ is nearer to 0 and ranges from about -17×10^{-4} to 69×10^{-4}.

Comparison of the results presented in the charts for the two models investigated shows that for all loadings for both models the spin is generally steep with some oscillation in pitch and roll and that the rate of rotation is fast. The recoveries from all spins were satisfactory by reversal of the rudder to full against the spin. It appears, therefore, that the modifications made on the present model from the original model had no noticeable adverse effect on the spin and recovery characteristics.

Stores were not tested on the present model, but based on the tests for the original model (ref. 1) it is not expected that stores would have any significant aerodynamic effect on the spin and recovery characteristics of the present modified model. The investigations with stores on the original model were made with the mass-parameter range $\frac{I_X - I_Y}{mb^2} = 117 \times 10^{-4}$ to -197×10^{-4} and it showed no significant effect on the spin or recovery. Since the range of mass parameters tested on the present model was $\frac{I_X - I_Y}{mb^2} = 94 \times 10^{-4}$ to -19×10^{-4}, it is not expected that the stores would have any more significant effect on the spin and recovery characteristics of the modified model than it did on the original model (ref. 1).

CONCLUSIONS

Based on the results of tests of a 1/20-scale model of the modified straight-wing, twin-boom, counter-insurgency airplane, the following conclusions regarding the spin and recovery characteristics of the airplane at 20 000 feet (6096 meters) are made:

1. The optimum recovery technique is movement of the rudder to full against the spin followed by movement of the elevators and ailerons to neutral about one-half turn later.

2. Recoveries from all erect and inverted spins will be satisfactory by using the optimum recovery technique.

3. Spins obtained with an aft center-of-gravity location will be somewhat slower in rotation and not quite as steep as the spins with the forward center-of-gravity location. However, the center-of-gravity location will have no appreciable effect on the recoveries.

4. Upper-surface spoilers will have little or no effect on the spin or recoveries.

5. When the inboard and outboard ailerons are used, somewhat faster spin rates will be obtained when ailerons are set with the spin. The recoveries will be satisfactory by using the optimum recovery technique.

6. A rocket mounted on the wing to give an antispin yawing moment of 27 600 ft-lb (37 421 m-N) about the Z body axis for at least 4.5 seconds (full scale) will be satisfactory for emergency recoveries from any spins obtained.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., July 2, 1970.

APPENDIX

TEST METHODS AND PRECISION

Model Testing Technique

General descriptions of model testing techniques, methods of interpreting test results, and correlation between model and airplane results are presented in reference 2.

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 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 dimensional characteristics of the model. (See ref. 2.) 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," 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 to be 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 ft/sec (>91 m/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 was 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 of 10 or more turns is indicated by ∞. When a model recovers without control movement (rudder held with the spin), the results are designated as "no spin."

For spin-recovery rocket tests, the minimum moment due to rocket thrust required to effect recovery within $2\frac{1}{4}$ turns from the criterion spin is determined. The rocket is fired for the recovery attempts by actuating the remote-control mechanism, and the rudder is held with the spin so that recovery is due to the rocket 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	±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 within an accuracy of $\pm 1^{\circ}$.

REFERENCES

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2. 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 MODIFIED AND ORIGINAL AIRPLANE DESIGNS

	Modified	Original (ref. 1)
Overall length, ft (m)	39.816 (12.14)	39.19 (11.95)
Nacelle span (distance between the nacelle center lines), in. (cm)	175 (444.5)	163 (414)
Sponson dihedral angle, deg	-24	0
Wing:		
Span, ft (m)	40 (12.19)	30 (9.14)
Area, ft^2 (m^2)	291 (27.03)	218 (20.25)
Mean aerodynamic chord, in. (cm)	87.25 (221.62)	87.25 (221.62)
Root chord, in. (cm)	87.25 (221.62)	87.25 (221.62)
Tip chord, in. (cm)	87.25 (221.62)	87.25 (221.62)
Taper ratio	1.0	1.0
Aspect ratio	5.51	4.13
Airfoil section	NACA 64_2A315 (modified)	NACA 64_2A315 (modified)
Incidence relative to fuselage reference line, deg	3.0	3.0
Dihedral, deg	0	0
Sweep of 0.25-chord line, deg	0	0
Flap and vane area (total), ft^2 (m^2)	38.0 (3.53)	34.17 (3.17)
Flap type	Double slotted	Double slotted
Flap chord, in. (cm)	24.8 (62.99)	24.8 (62.99)
Flap maximum deflection, deg	40.0	
Aileron:		
Type	Plain balance	
Span (outboard plus inboard), in. (cm)	78.75 (200.03)	34.13 (86.69)
Total area (outboard plus inboard), ft^2 (m^2)	14.42 (1.34)	8.30 (0.77)
Chord, in. (cm)	13.1 (33.27)	17.45 (44.32)
Spoilers:		
Type	Plate	
Span, in. (cm)		
Upper	49.75 (126.37)	59.8 (151.89)
Lower	30.37 (77.14)	0
Chordwise location, percent wing chord	58.7	58.7
Maximum projection, percent wing chord	7.625	

TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE MODIFIED AND ORIGINAL AIRPLANE DESIGNS – Concluded

	Modified	Original (ref. 1)
Horizontal tail:		
Span, in. (cm)	175 (444.5)	163 (414)
Area, ft^2 (m^2)	70.48 (6.55)	70.3 (6.53)
Chord, in. (cm)	58.0 (147.3)	62.2 (157.99)
Taper ratio	1.0	1.0
Aspect ratio	3.02	2.62
Airfoil section	NACA 66-012 (modified)	NACA 64_1A412 (modified inverted)
Incidence angle to fuselage reference line, deg	0	2.0
Sweep of 25 percent chord, deg	0	0
Mean aerodynamic chord, in. (cm)	58.0 (147.3)	62.2 (157.99)
Elevator:		
Area, ft^2 (m^2)	18.9 (1.76)	24.90 (2.31)
Span, in. (cm)	167.62 (425.75)	163 (414)
Chord (aft of hinge line), percent chord	28.0	
Chord, in. (cm)	16.2 (41.15)	22 (55.88)
Trim tab, in. (cm)		
Span	167.62 (425.75)	
Chord	3.75 (9.53)	
Vertical tail (twin):		
Span, in. (cm)	86 (218.44)	86 (218.44)
Area (each), ft^2 (m^2)	34.88 (3.24)	34.88 (3.24)
Chord, in. (cm)	58.4 (148.34)	58.4 (148.34)
Taper ratio	1.0	1.0
Aspect ratio	1.47	1.47
Airfoil section	NACA 64_1A012	NACA 64_1A012
Sweep of 0.25-chord line, deg	32	32
Rudder:		
Area (each), ft^2 (m^2)	10.7 (0.99)	11.55 (1.07)
Span tip chord, in. (cm)	77.71 (197.38)	69.4 (176.3)
Chord, in. (cm)		24 (60.96)

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR TYPICAL LOADINGS ON THE 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	Loading description	Weight, lb (N)	Center-of-gravity location		Relative density, μ		Moments of inertia, slug-ft^2 (kg-m^2)			Inertia parameters		
			$x/\bar{c}$	$z/\bar{c}$	Sea level	Altitude, 20 000 ft (6 096 m)	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 values											
1	Clean airplane; sponsons on; 60-percent fuel	9 493 (42 227)	0.238	0.178	10.65	19.99	12 304 (16 682)	12 944 (17 549)	23 036 (31 232)	-14×10^{-4}	-214×10^{-4}	228×10^{-4}
2	Clean airplane; sponsons off; 60-percent fuel	8 925 (39 700)	0.240	0.209	10.00	18.78	11 964 (16 221)	12 696 (17 213)	22 911 (31 063)	-17×10^{-4}	-230×10^{-4}	246×10^{-4}
3	Asymmetrical sidewinder; sponsons on; 60-percent fuel	9 979 (44 389)	0.240	0.175	11.20	21.02	15 172 (20 570)	13 050 (17 693)	25 996 (35 245)	-43×10^{-4}	-261×10^{-4}	218×10^{-4}
4	Symmetrical sidewinder; sponsons on; 60-percent fuel	10 219 (45 456)	0.240	0.172	11.45	21.49	16 635 (22 554)	13 121 (17 790)	27 522 (37 314)	69×10^{-4}	-284×10^{-4}	214×10^{-4}
5	(4) MK 82 stores; 60-percent fuel	11 593 (51 568)	0.240	0.068	13.01	24.41	13 720 (18 602)	14 130 (19 158)	23 548 (31 926)	-7×10^{-4}	-163×10^{-4}	171×10^{-4}
6	Asymmetrical sidewinder; (4) MK 82 stores; 60-percent fuel	12 079 (53 730)	0.241	0.070	13.55	25.42	16 590 (22 493)	14 223 (19 284)	26 513 (35 946)	39×10^{-4}	-205×10^{-4}	165×10^{-4}
7	Symmetrical sidewinder; (4) MK 82 stores; 60-percent fuel	12 319 (54 798)	0.242	0.070	13.84	25.97	18 044 (24 464)	14 301 (19 389)	28 034 (38 008)	61×10^{-4}	-224×10^{-4}	163×10^{-4}
	Model values											
1	Clean airplane; sponsons on; 60-percent fuel	9 511 (42 307)	0.230	0.187	10.67	20.03	12 278 (16 647)	13 193 (17 887)	22 865 (31 000)	-19×10^{-4}	-205×10^{-4}	224×10^{-4}
8	Clean airplane; sponsons on; 60-percent fuel; aft center of gravity	9 737 (43 312)	0.300	0.200	10.92	20.50	12 745 (17 280)	13 137 (17 811)	23 168 (31 411)	-8×10^{-4}	-207×10^{-4}	215×10^{-4}
9	Clean airplane; sponsons on; wing heavy condition	9 511 (42 307)	0.230	0.187	10.67	20.03	17 648 (23 927)	13 193 (17 887)	22 865 (31 000)	94×10^{-4}	-318×10^{-4}	224×10^{-4}

TABLE III.- EFFECT OF SPOILERS AND INBOARD AND OUTBOARD AILERONS ON THE SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Model loading 1, table II; recovery was attempted by full rudder reversal unless otherwise noted. (Recovery was attempted from and developed-spin data were presented for rudder full with the spin.)]

Spin	Spin block	Control setting for spin		Roll control used	Spin condition (a)				Turns for recovery	Remarks
		Elevator	Ailerons		V, fps (m/sec)	α, deg	ϕ, deg	Ω, rps		
1		35° up	20° against	Outboard ailerons only	300 (91)	23	4 U 3 D	0.49	$\frac{1}{2}$, $\frac{3}{4}$	
2		35° up	20° against	Outboard ailerons plus spoilers	300 (91)	23	4 U 3 D	0.49	-------	Spoilers had no effect
3		35° up	25° against	Outboard and inboard ailerons plus spoilers	289 (88)	24	7 U 9 D	0.40	-------	Inboard ailerons plus increase deflection slowed the spin rate of rotation
4		35° up	25° against	Outboard and inboard ailerons only	289 (88)	24	7 U 7 D	0.40	-------	Spoilers had no effect
5		35° up	20° with	Outboard ailerons only	≈300 (≈91)	19 34	3 D 15 D	≈0.52	$\frac{3}{4}$, 1	A whipping type of spin
6		35° up	25° with	Outboard and inboard ailerons only	≈278 to 324 (≈85 to 99)	21 38	0 21 D	0.62	1, $1\frac{1}{4}$, >2	Inboard ailerons plus increase deflection increased the spin rate of rotation

[a]Oscillatory spin. Range or average values given.

TABLE IV.- ROCKET RECOVERY SPIN TESTS ON THE 1/20-SCALE MODEL OF THE AIRPLANE WITH ROCKETS SIMULATING YAWING MOMENT

[Recovery attempted by firing rockets on wings; right erect spins; model values have been converted to corresponding full-scale values. Design values on the airplane are also listed.]

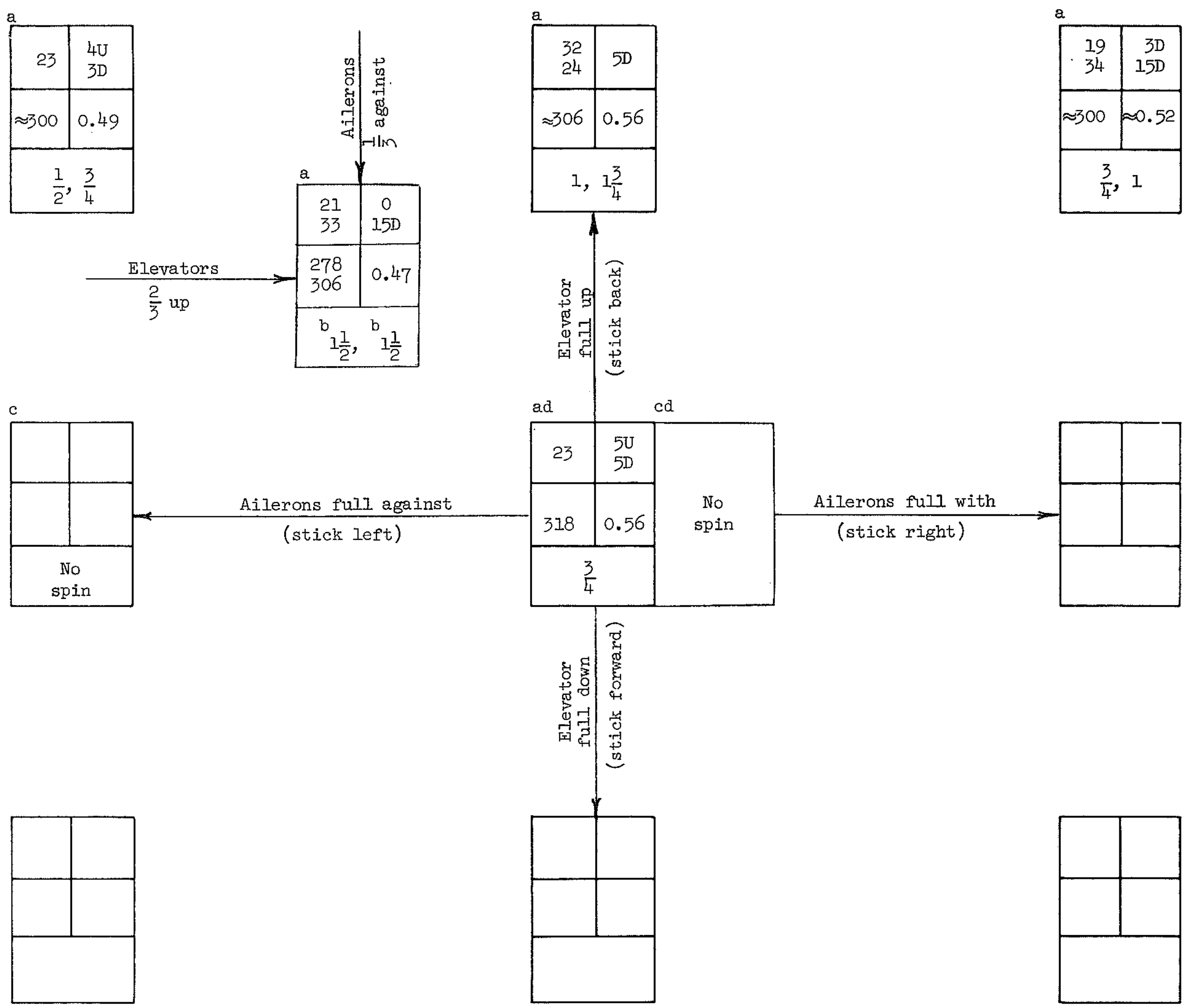
Spin	Control setting for spin			Rocket thrust, lb (N)		Location on Y-axis, in. (cm)		Firing time, sec		Moment applied, ft-lb (m-N)		Impulse, ft-lb-sec (m-N-sec)		Inclination of thrust line to fuselage reference line	Turns for recovery
	Rudder	Elevator	Aileron	Airplane	Model	Airplane	Model	Airplane	Model	Airplane	Model	Airplane	Model		
Model loading $\frac{I_X - I_Y}{mb^2} = -19 \times 10^{-4}$; c.g. = $0.23\bar{c}$; loading 1 (table II)															
1	25° with	23° up	0°	1440 (6405)	1600 (7117)	230 (584)	207 (526)	3.4	4.47	27 600 (37 421)	27 600 (37 421)	94 000 (127 445)	123 000 (166 763)	0°	$\frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1\frac{1}{4}$
2	25° with	23° up	0°	1440 (6405)	800 (3559)	230 (584)	207 (526)	3.4	4.47	27 600 (37 421)	13 800 (18 710)	94 000 (127 445)	61 000 (82 704)	0°	$1\frac{1}{4}, \infty, \infty, \infty$
Model loading $\frac{I_X - I_Y}{mb^2} = -8 \times 10^{-4}$; c.g. = $0.30\bar{c}$; loading 8 (table II)															
3	25° with	23° up	8° against	1440 (6405)	1600 (7117)	230 (584)	207 (526)	3.4	4.47	27 600 (37 421)	27 600 (37 421)	94 000 (127 445)	123 000 (166 763)	0°	$\frac{1}{2}, \frac{1}{4}$
Model loading $\frac{I_X - I_Y}{mb^2} = 94 \times 10^{-4}$; c.g. = $0.23\bar{c}$; loading 9 (table II)															
4	25° with	23° up	0°	1440 (6405)	1600 (7117)	230 (584)	207 (526)	3.4	4.47	27 600 (37 421)	27 600 (37 421)	94 000 (127 445)	123 000 (166 763)	0°	$\frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{3}{4}$
5	25° with	23° up	0°	1440 (6405)	1600 (7117)	230 (584)	140 (356)	3.4	4.47	27 600 (37 421)	18 667 (25 309)	94 000 (127 445)	83 441 (113 129)	0°	1

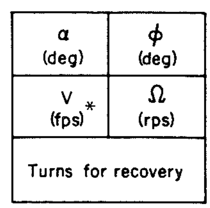
CHART 1.– SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted. Recovery was attempted from and developed-spin data were presented for rudder full with the spin.]

Airplane	Attitude Erect	Direction Right	Loading 1 (see table II) Clean airplane with sponsons on and 60-percent fuel.		
Slats	Flaps		Center-of-gravity position, 0.23$\bar{c}$	Altitude 20 000 ft (6096 m)	Maximum aileron deflection ±20°

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





[a]Oscillatory spin. Range or average values given.
[b]Recovery by reversing rudder to $\frac{2}{3}$ against the spin.
[c]Goes steep and dives out.
[d]Two conditions possible.

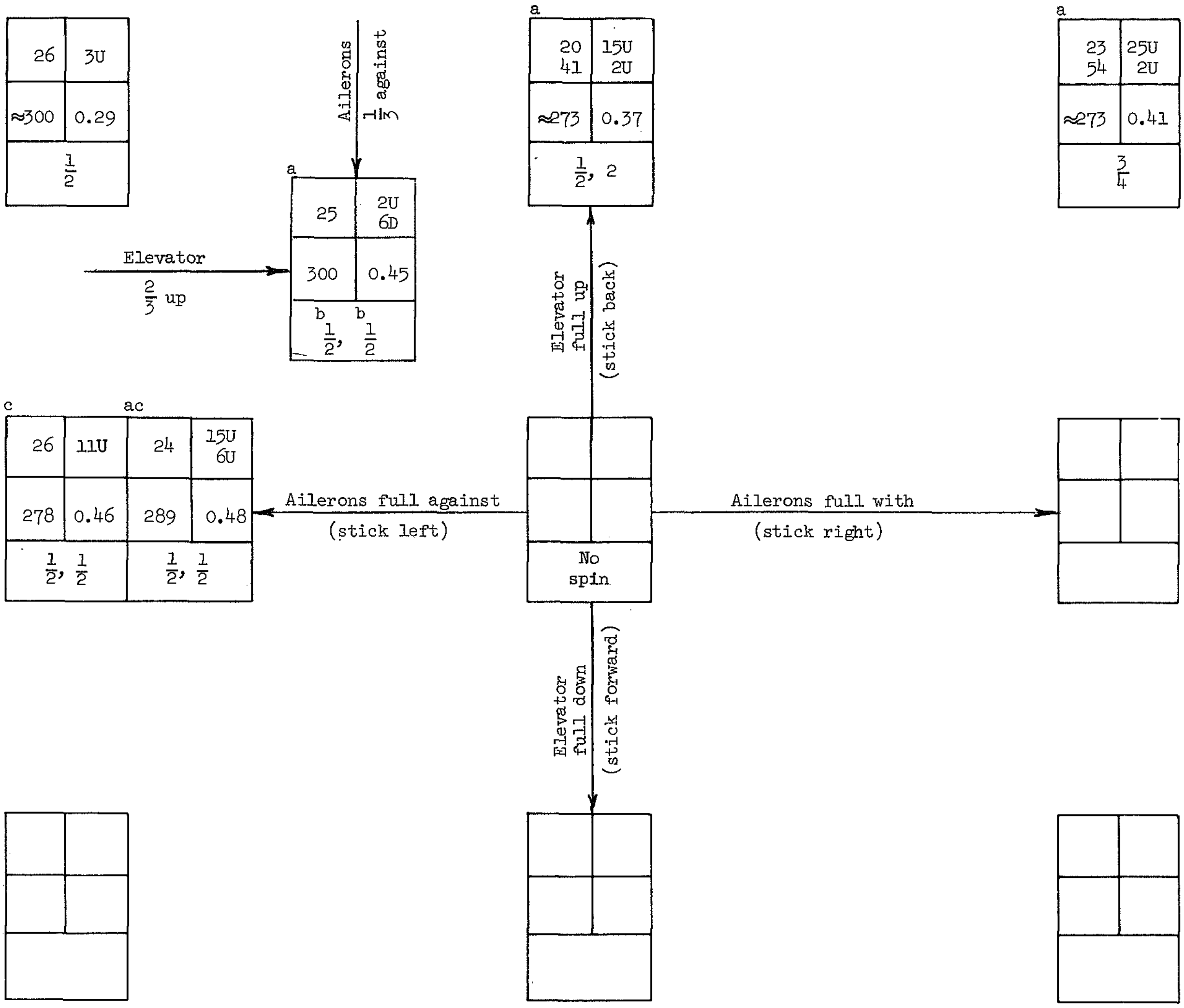
*To convert to m/sec, multiply by 0.3048.

CHART 2.— SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

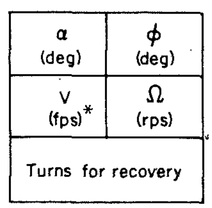
[Recovery attempted by full rudder reversal unless otherwise noted. Recovery was attempted from and developed-spin data were presented for rudder full with the spin.]

Airplane	Attitude	Direction	Loading 8 (see table II)	Clean airplane with sponsons on and 60-percent fuel. Aft center of gravity.	
	Erect	Right			
Slats	Flaps		Center-of-gravity position, 0.30c̄	Altitude, 20 000 ft (6096 m)	Maximum aileron deflection ±25°

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



[a]Oscillatory spin. Range or average values given.
[b]Recovery by reversing rudder to 2/3 against the spin.
[c]Two conditions possible.



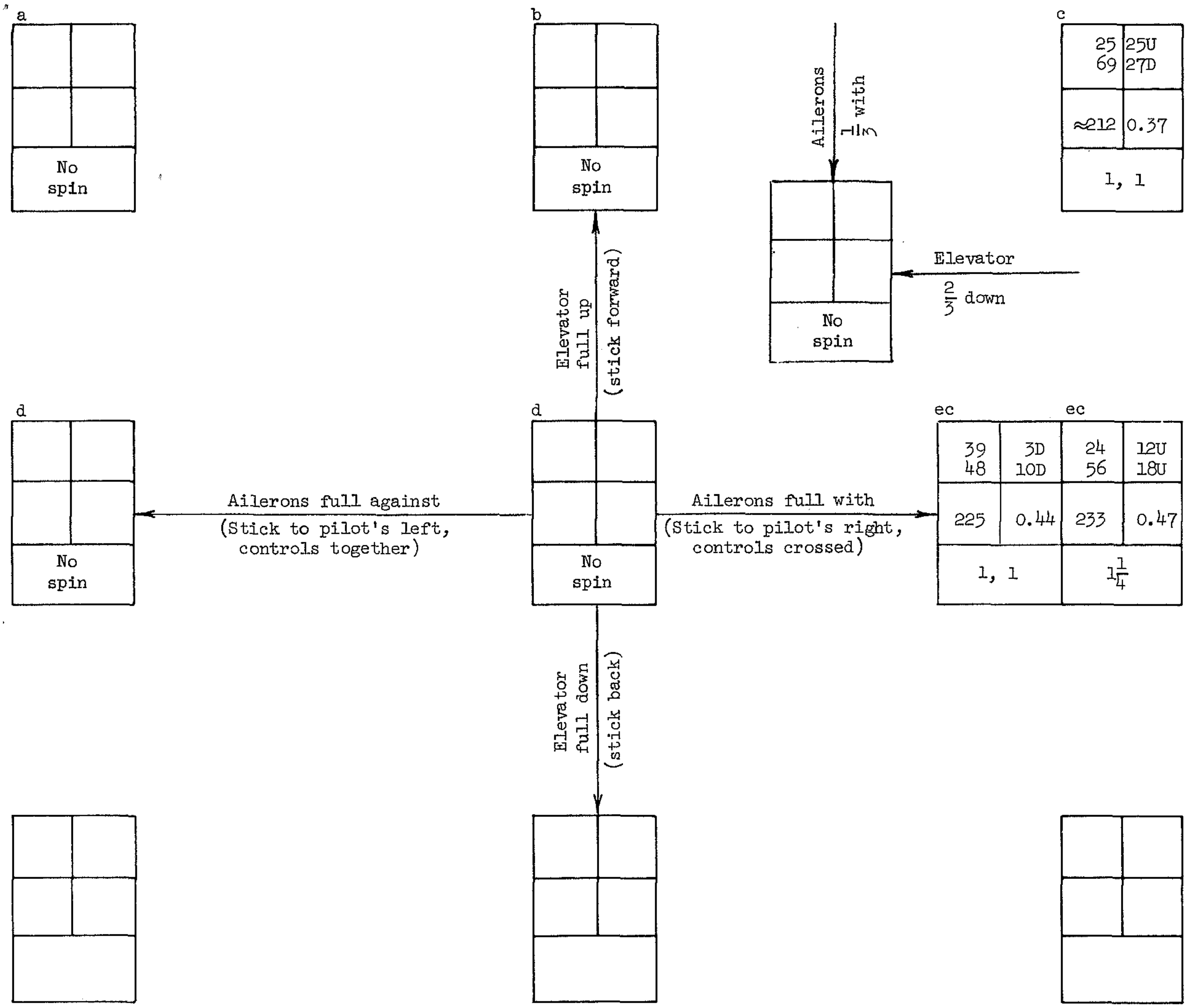
*To convert to m/sec, multiply by 0.3048.

CHART 3.– SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted. Recovery was attempted from and developed-spin data were presented for rudder full with the spin.]

Airplane	Attitude Inverted	Direction To pilot's left	Loading 8 (see table II) Clean airplane with sponsons on and 60-percent fuel. Aft center of gravity.		
Slats	Flaps		Center-of-gravity position, 0.30c̄	Altitude, 20 000 ft (6096 m)	Maximum aileron deflection ±25°

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



[a]May start spinning in opposite direction or become erect.
[b]Dives out.
[c]Oscillatory spin. Range or average values given.
[d]Dives out and goes into an erect spin.
[e]Two conditions possible.

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

*To convert to m/sec, multiply by 0.3048.

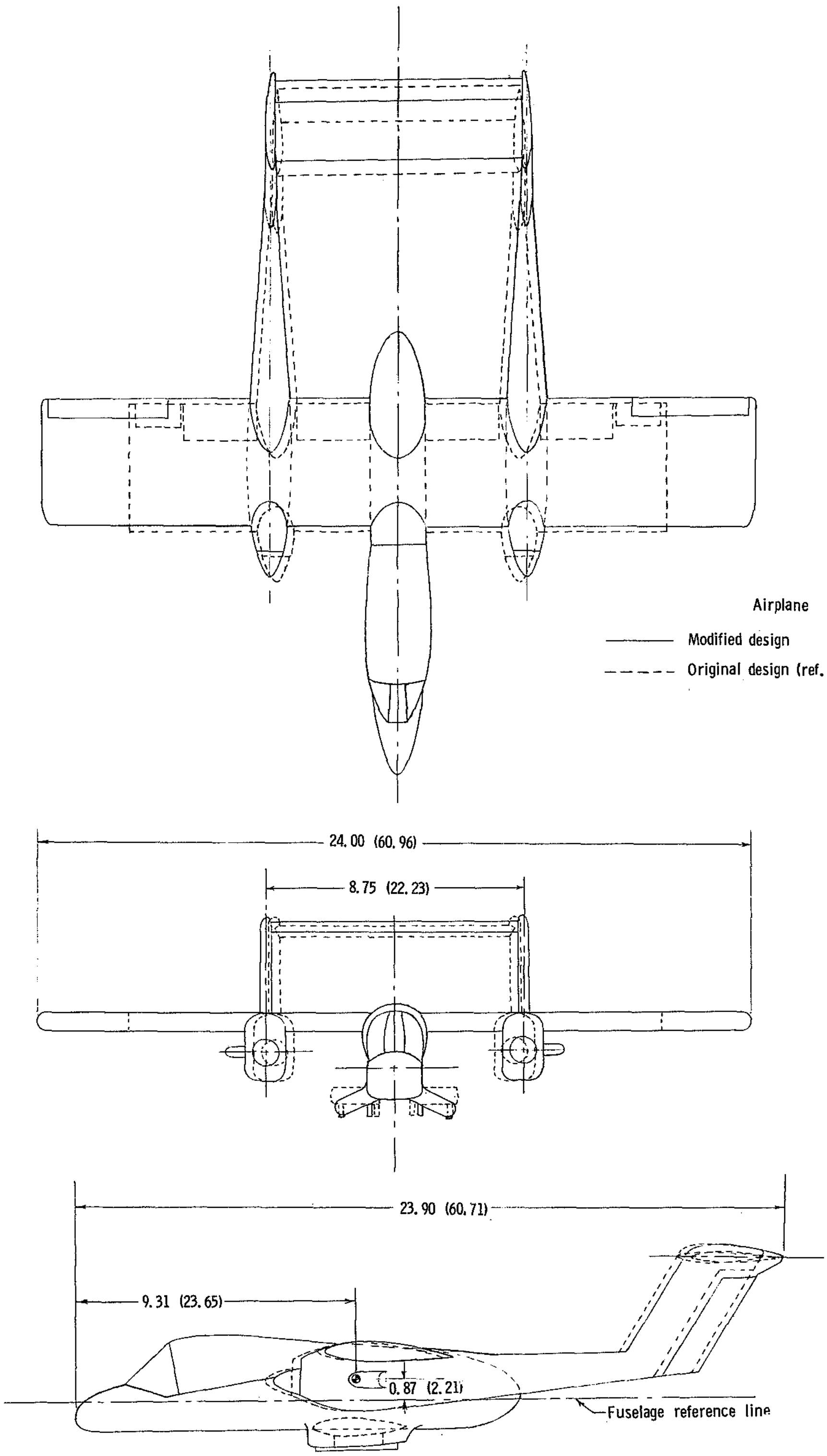
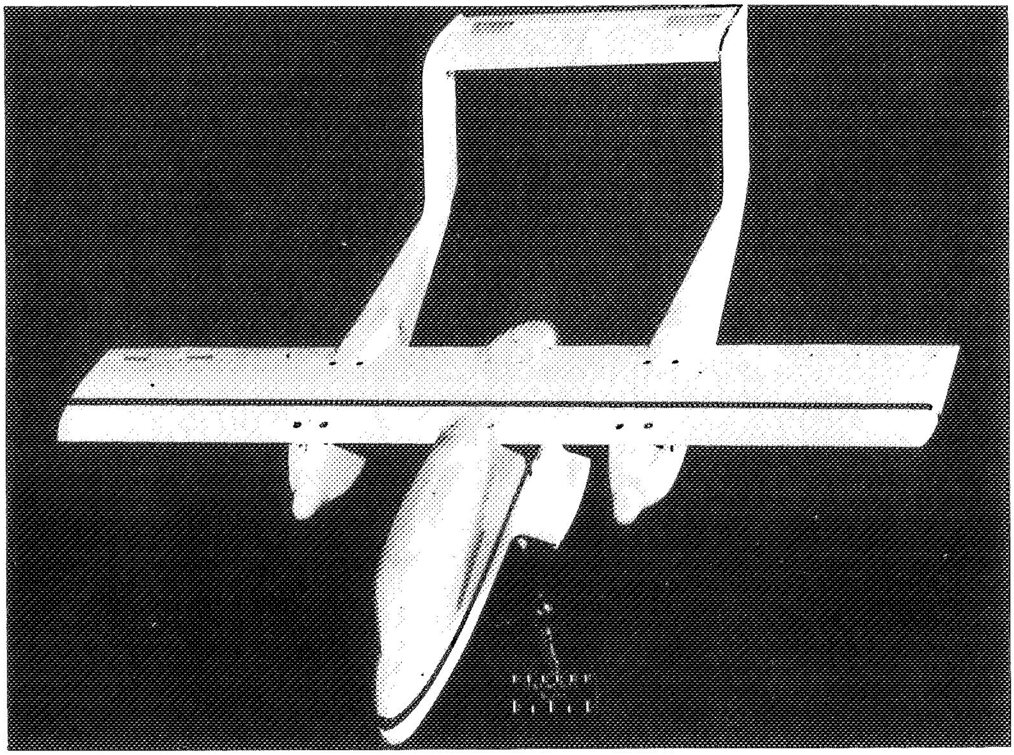
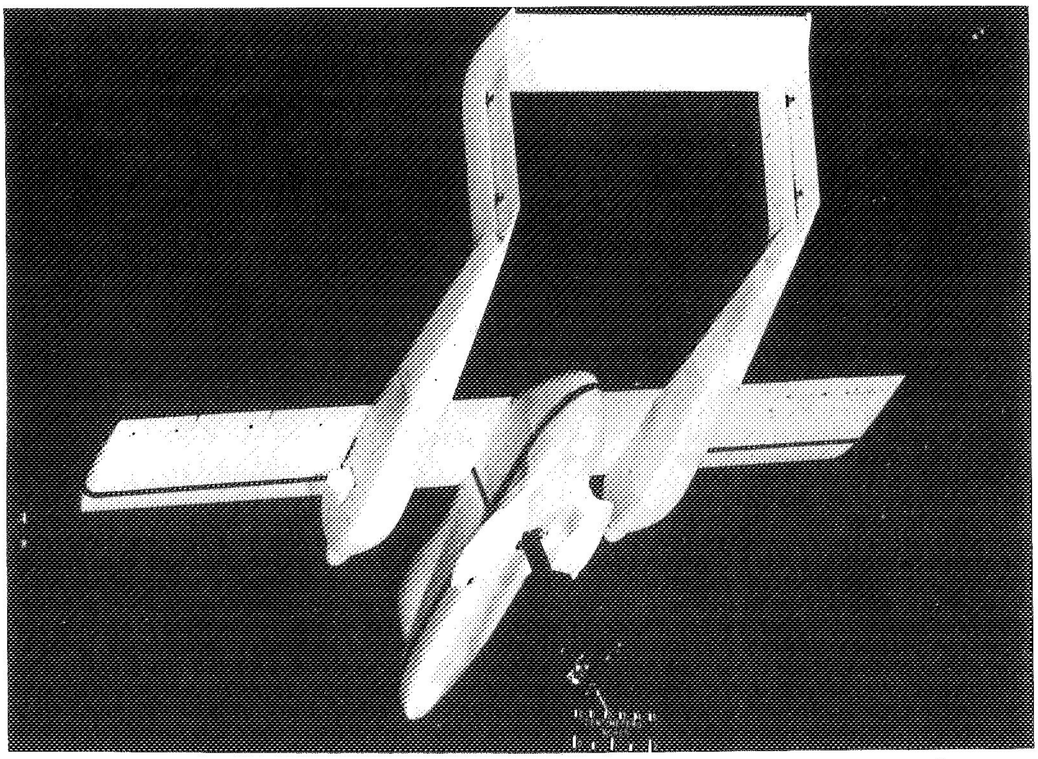


Figure 1.- Three-view drawing of the modified 1/20-scale model of the straight-wing, twin-boom, counter-insurgency airplane with a comparison drawing of the original design (ref. 1). Center-of-gravity position shown is 0.23$\bar{c}$. All dimensions are in inches, parenthetically in centimeters.



L-67-8935



L-67-8937

Figure 2.- The 1/20-scale model of the airplane as tested in the Langley spin tunnel.

NASA-Langley, 1970 —— 12 L-7142

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