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SPIN-TUNNEL TESTS OF A 1/57.33-SCALE MODEL OF THE NORTHROP XB-35 AIRPLANE

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NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

SPIN-TUNNEL TESTS OF A 1/57.33-SCALE MODEL OF THE NORTHROP XB-35 AIRPLANE

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SUMMARY

At the request of the Army Air Forces, Materiel Command, a 1/57.33-scale model of the Northrop XB-35 airplane has been tested in the NACA free-spinning tunnel in order to determine the spin characteristics and the tumbling tendencies of the airplane. The XB-35 airplane is a large four-engine bomber of the flying-wing type. It has elevon control surfaces which are used as ailerons or elevators. The airplane is equipped with conventional split flaps whose pitching moments are trimmed out by pitch flaps at the wing tips. The rear portions of the pitch flaps are split and can be deflected as rudders.

The spin tests indicated that for the normal loading condition the model would not spin in the direction of the rudder for either the clean or the landing condition unless the wheel was set over with the rudder. The results indicated that recovery from this spin could be effected by pushing the stick forward and reversing the wheel, leaving the rudder with the spin. Reversing the rudder retarded recovery. The spin characteristics were not appreciably affected by changes in the loading condition, although moving the center of gravity forward to 20 percent of the mean aerodynamic chord was beneficial.

The model would tumble in the normal loading condition but would not tumble when the center of gravity was moved forward to 20 percent of the mean aerodynamic chord.

INTRODUCTION

The Northrop XB-35 airplane is a four-engine bomber of the flying-wing type with pusher propellers. NACA low-drag airfoil sections are used in the wing design. For controlling the airplane, combination elevators and ailerons termed "elevons" are deflected in the same direction for longitudinal control and differentially for lateral control. Pitch flaps outboard of the elevons are used for additional longitudinal control to trim the airplane when split flaps are deflected for landing or take-off. The rear portions of the pitch flaps are split and can be deflected up and down equally independent of the pitch-flap position to act as rudders for directional control. As was requested by the Army Air Forces, Materiel Command, tests were performed in the NACA free-spinning tunnel to determine the spin characteristics and tumbling tendencies of a 1/57.33-scale model of the airplane.

For the tests, the normal loading condition of the model corresponded to that of the airplane with maximum bomb load and outboard fuel. The spin characteristics of the model in the clean condition were determined for the normal loading and for various alternate loadings. The landing condition was also investigated. The tumbling tendencies were determined for the model in the normal loading condition and also with the center of gravity moved forward of normal. The effects on tumbling of pitch-flap setting, landing-flap deflections, rudder deflections, slots, and spoilers were investigated.

SYMBOLS

S wing area, square feet

b wing span, feet

c wing chord, feet

$\bar{c}$ mean aerodynamic chord, feet

$x/\bar{c}$ ratio of distance of the center of gravity rearward of leading edge of the mean aerodynamic chord to the mean aerodynamic chord

$z/\bar{c}$	ratio of distance from the center of gravity to the wing-root chord line to the mean aerodynamic chord, positive when the center of gravity is below the wing-root chord line
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about the X, Y, and Z body axes, slug-feet^2
$\dfrac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\dfrac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\dfrac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
C_l	rolling-moment coefficient, $\dfrac{\text{Rolling moment}}{\frac{1}{2}\rho V^2 bS}$
C_n	yawing-moment coefficient, $\dfrac{\text{Yawing moment}}{\frac{1}{2}\rho V^2 bS}$
ρ	air density, slugs per cubic foot
α	acute angle between the vertical and the wing-root chord line (approximately equal to the absolute value of angle of attack at the plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, revolutions per second

σ helix angle, angle between the flight path and the vertical, degrees (For this model the absolute value of the helix angle was approximately 6°)

β approximate angle of sideslip at the center of gravity, degrees (Sideslip is inward when the inner wing is down by an amount greater than the helix angle)

APPARATUS AND METHODS

Model

The 1/57.33-scale model of the Northrop XB-35 airplane used in the tests was furnished by the Army Air Forces, Materiel Command and was prepared for testing by the Langley Memorial Aeronautical Laboratory. The dimensional characteristics of the airplane are given in table I. A three-view drawing of the model with the landing gear extended and slots open is given in figure 1. Propellers were not simulated on the model for the tests. Photographic views of the model are shown in figure 2.

The model was ballasted with lead weights to maintain dynamic similarity to the airplane at an altitude of 20,000 feet (ρ = 0.001267 slug per cubic foot). A remote-control mechanism was installed in the model to actuate the controls for the recovery tests.

Wind Tunnel and Testing Technique

The tests were performed in the NACA 20-foot free-spinning tunnel, which is similar in operation to the 15-foot tunnel described in reference 1.

The data presented were determined by the methods described in reference 1 and have been converted to corresponding full-scale values. The turns for recovery are measured from the time the controls are moved until the spin rotation ceases. A recovery which requires more than two turns is considered unsatisfactory. For the conditions for which the model recovered when launched in a spinning attitude, the data are recorded as "No spin." For the spins which appeared steep and had a very high rate of descent it was difficult to obtain quantitative data, and the spin is recorded as a "steep spin."

PRECISION

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

α, deg	±1
ϕ, deg	±1
V, percent	±2
Ω, percent	±3
Turns for recovery	$\pm\frac{1}{4}$ turn when obtained from film records $\pm\frac{1}{2}$ turn when obtained from observations

The preceding limits may have been exceeded for certain cases in which it was difficult to handle the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

Comparison between model and airplane spin results (references 1 and 2) indicated that the spin-tunnel results were not always in complete agreement with the full-scale airplane results. In general, models spin at a somewhat smaller angle of attack, at a somewhat higher rate of descent, and with from 5° to 10° more outward sideslip. The comparison made in reference 2 showed that 80 percent of the model recovery tests predicted satisfactorily the corresponding full-scale recovery and that 10 percent overestimated and 10 percent underestimated the full-scale recoveries.

Because of repeated damages to the model during the tests, the weight and mass distribution varied by the following values:

Weight	2 percent low to 1 percent high
Center of gravity . .	$0.01\bar{c}$ forward to $0.03\bar{c}$ rearward
I_X	5 percent low to 10 percent high
I_Y	5 percent low to 12 percent high
I_Z	5 percent low to 13 percent high

TEST CONDITIONS

Spin tests were made for the conditions of the model listed in table II. The normal loading condition of the model corresponded to the following mass distribution of the full-scale airplane with the landing gear retracted:

Weight, lb	155,000
$x/\bar{c}$	0.275
$z/\bar{c}$	-0.014
I_X, slug-ft^2	3,380,000
I_Y, slug-ft^2	433,500
I_Z, slug-ft^2	3,769,000
$\dfrac{I_X - I_Y}{mb^2}$	207×10^{-4}
$\dfrac{I_Y - I_Z}{mb^2}$	-234×10^{-4}
$\dfrac{I_Z - I_X}{mb^2}$	27×10^{-4}

The elevon deflections used are shown on figure 3. It may be noted that a longitudinal movement of the stick (wheel neutral) deflects both elevons equally in the same direction, whereas a lateral movement of the wheel deflects one elevon up and the other one down.

The maximum control deflections used were:

Elevons as elevators, deg	20 up, 10 down
Elevons as ailerons, deg	15 up, 15 down
Pitch flaps, deg	30 up, 15 down
Rudders, deg	60 up, 60 down

The rudder deflections were independent of pitch-flap settings. For example, when the pitch flaps were 10° up, pushing the right rudder pedal forward (rudder with a right spin) deflected the split rudders on the right pitch flap 70° up and 50° down from the wing chord while the rudders on the left pitch flap remained undeflected.

For the clean condition with landing gear retracted, variations in mass distribution were tested in order to allow for the limits of accuracy of the computed full-scale and model values and also to allow for any re-arrangement of loading which might lead to a spinning condition from which recovery might be slower.

In the landing condition, the landing flaps were deflected 60°, the landing gear was extended, the pitch flaps were deflected up 30°, and the leading-edge wing slots were opened.

For a few tumbling tests, two alternate sets of spoilers were tested, mounted perpendicular to the wing surface. One set was installed on the top and bottom of the wing along the 15-percent wing chord line and extended from the wing tips inboard 60 percent of the semispan. The height of the spoilers was 10 percent of the wing chord. The second set was installed along the top and bottom of the wing along the 15-percent wing chord line and extended from the root section outboard 60 percent of the semispan. The height of these spoilers was 6 percent of the wing chord.

RESULTS AND DISCUSSION

The results of the spin tests are presented in charts 1 to 9. The steady-spin data given on the charts have been converted to full-scale values for the airplane operating at an altitude of 20,000 feet. Data are given for α, the angle of the wing chord to the vertical, ϕ, the angle of the span axis to the horizontal, V, the rate of descent, and Ω, the angular velocity about the spin axis. The angle of sideslip β at the center of gravity may be determined approximately from the relation $\beta = \phi - \sigma$, where $\sigma = 6^\circ$ for this model. Preliminary tests indicated that results obtained for right and left spins were very similar. All data presented herein are in terms of right spins, that is, for the airplane turning to the pilot's right. The results of the tumbling tests are presented in tables III and IV.

Spin Tests - Clean Condition

Normal loading.- The test results for the model in the clean condition, normal loading, are shown on chart 1. At the normal spinning control configuration (stick full back, wheel neutral, and rudders full with the spin) the model would not spin. A moderately steep spin, which appeared quite normal in spite of the unconventionality of the model, was obtained when the stick was full back and the wheel was set with the spin (wheel right in a right spin). Recovery from this spin could not be effected by rudder reversal. When the stick was neutral and the wheel was full with the spin, the model spun steeply with an oscillation in pitch and may have oscillated out of the spin if it had not struck the net first. The model would not spin for any other combination of stick-wheel positions tested.

When the rudders were neutral, spins were obtained for all stick positions when the wheel was full with the spin and also when the stick was neutral or full forward and the wheel was neutral.

When the rudders were against the spin, the model spun for all stick and wheel positions except wheel full against the spin, stick neutral or full forward. In a few cases, recovery was attempted by moving the rudders to full with the spin. No recovery was effected from the spin with the stick back and the wheel with the spin, but the indications were that recovery could be effected in this manner from the other spins obtained. These results indicate that, for the XB-35 airplane, recovery by the conventional technique - rudder reversal followed by forward movement of the stick - would not be possible.

Results of tests made with the model in the clean condition but with the slots open are presented on chart 2. With the rudder full with the spin, the results obtained were similar to those obtained with the slots closed. With the rudder full against the spin, however, the model spun for fewer control settings than with the slots closed.

The effects of maximum pitch-flap setting were determined with the model in the normal loading condition. Deflecting the pitch flaps up had little effect on the spin characteristics, and the results are not presented in chart form. The results obtained with the pitch flaps full down are presented on chart 3. With the rudders full with the spin, the results were similar to those obtained with the pitch flaps neutral. With the rudders full against the spin, however, the model spun for fewer control settings than with the pitch flaps neutral. Use of the conventional recovery technique, therefore, would probably have given satisfactory recovery.

Mass variations.- The effects of changes in the mass distribution of the model in the clean condition are given in charts 4 to 7. Increasing the longitudinal loading (I_Y and I_Z increased by 30 percent of I_Y) was adverse in that the model spun for more rudder-with control settings than for normal loading. Recoveries by reversing the rudder from the spins obtained were unsatisfactory.

Moving the center of gravity 7.5 percent of the mean aerodynamic chord forward of normal (that is, to 20 percent mean aerodynamic chord) was beneficial in that, when the rudders were against the spin, the model would spin only with the stick back. Recovery by use of the conventional technique, or by elevator reversal alone, would probably have been satisfactory.

Moving the center of gravity 5.8 percent of the mean aerodynamic chord rearward of normal (that is, to 33.3 percent mean aerodynamic chord) was adverse in that when the rudders were with the spin the model spun for all control settings except when the wheel was full against the spin. A satisfactory recovery by rudder reversal alone was effected only from the spin at the normal control configuration. When the rudders were against the spin, spins were obtained only when the wheel was full with the spin.

With the center of gravity moved 11.6 percent of the mean aerodynamic chord rearward of normal (that is, at 39.1 percent mean aerodynamic chord), the model spun for most control positions. Recoveries obtained were generally satisfactory except from the spin made with the wheel full with the spin, stick neutral or full back. The model would not spin for any control position when the rudder was against the spin.

Extending mass along the wing (I_X and I_Z increased by 30 percent of I_X), retracting mass along the wing (I_X and I_Z decreased by 10 percent of I_X), or retracting mass longitudinally (I_Y and I_Z decreased by 30 percent of I_Y) had no appreciable effect on the spin characteristics.

Explanation of results.- Inasmuch as the results were unusual in that, for most conditions, spins were obtained for more stick-wheel positions with the rudder against the spin than with the rudder with the spin, special tests were made to measure the aerodynamic moments produced by the rudders through a large angle-of-attack range on the free-flight tunnel balance in order to determine if this unusual behavior could be explained by the aerodynamic moments. For these tests, the elevons were neutral and the rudders on the left wing tip were fully extended while those on the right wing tip were neutral. Increments of yawing- and rolling-moment coefficients with respect to body axes due to the rudders are presented on figure 4. The yawing-moment curve obtained was not unusual, and the yawing-moment coefficient increased with angle of attack. The important point brought out by the figure is that left rudder gives a large rolling moment to the right. If the data on figure 4 are considered to be for rudder against a right spin, it can be seen that for rudder against the spin the rolling moment would tend to roll the model with the spin.

The results of the spin tests of the model in the clean condition (charts 1 to 7) were in general agreement with the findings of the balance tests and indicate, therefore, that the aerodynamic rolling moments produced by the rudder are a possible explanation for the differences between the rudder-with and the rudder-against spin characteristics. The results of the spin tests of the model with the center of gravity rearward of normal (charts 6 and 7), however, are in disagreement with the general trend in that the model would spin for fewer control configurations when the rudder was against the spin than when it was with the spin.

Inverted spins.- Except for the nacelles, the model was essentially symmetrical erect and inverted. It was thought that the erect and inverted spin characteristics would have been similar except, of course, for the differences in control settings. Inverted-spin tests were accordingly not made, but it is believed that rudder-with spins would probably have been obtained only with the wheel to the opposite side from the rudder (controls crossed) and the stick neutral or full forward. Recovery by rudder reversal would probably have been impossible. The model would probably have spun for most stick-wheel positions with the rudders against the spin.

Spin Tests - Landing Condition

The results obtained with the model in the landing condition are presented on chart 8. With the rudder set with the spin, the results were similar to those obtained in the clean condition. When the rudder was against the spin, however, spins were obtained for all elevon settings. Results of tests made with the model in the landing condition but with slots closed were generally similar to those obtained with slots open (chart 9).

The spin test results as a whole indicated that moving the rudders to against the spin was generally ineffective in producing recovery from spins. It appears that, for optimum recovery from erect spins, the rudders should be kept full with the spin, the stick should be put full forward, and the wheel should be moved full against the spin. The model would not spin with these control positions for any condition tested, and it is believed that rapid recoveries would be effected by using this control manipulation. For inverted spins it is recommended that the rudder be kept with the spin, the stick be put full back, and the wheel be moved to the same side as the rudder (controls together).

Tumbling Tests

Normal loading.- Tumbling tests were made with the model in the normal loading, clean condition with the pitch flaps and rudders neutral. Results obtained when the model was released without rotation in a nose-up attitude simulating a whip stall are presented in table III. When the stick was full forward the model sometimes started to tumble, that is, rotate about the lateral axis, and sometimes executed a series of extreme oscillations in pitch during which the model would pitch through almost ±180° measured from the nose-down attitude. This oscillation appeared to be only lightly damped. For stick neutral or back, the model did not start to tumble but went into dives with extreme oscillations in pitch. The results of tests made in which the model was launched with an initial pitching rotation are presented in table IV. When launched with an initial pitching rotation, the model continued to tumble regardless of stick-wheel position. This was true when the model was launched with either positive or negative pitching rotation. The vertical component of velocity during tumbling was calculated to be approximately 224 feet per second, full scale, and the horizontal component of velocity, approximately 91 feet per second, full scale. The rate of rotation was approximately 0.56 revolution per second, full scale.

Mass variation.- With the center of gravity moved forward 7.5 percent of the mean aerodynamic chord (that is, at 20 percent of the mean aerodynamic chord), the model generally would not continue to tumble when launched with an initial pitching rotation but would go into a dive with extreme oscillations in pitch.

Effect of rudders as dive brakes.- With both rudders fully extended as dive brakes, the model continued to tumble when launched with initial rotation except when the stick was full back and the model was launched with negative pitching rotation. For this condition, the model sometimes stopped tumbling and went into an oscillatory dive and sometimes stopped and then started to tumble with positive pitching. The behavior of the model with the rudders on one wing open was generally the same as with both rudders open.

Effect of pitch-flap setting.- With both pitch flaps deflected up 30°, the results obtained were similar to those with both rudders fully extended. With both pitch flaps deflected down 15°, the model continued tumbling regardless of the direction of initial pitching rotation or of stick and wheel position.

Effect of landing flaps.- With the landing flaps deflected, the model generally continued tumbling. With the pitch flaps set full down and the landing flaps deflected, the model would not tumble when launched with positive pitching rotation with the stick neutral or full forward. Similar results were obtained when the rudders on one wing were opened and the landing flaps were deflected.

Outboard spoilers.- Installation of outboard spoilers on the wing had no appreciable effect on tumbling.

Slots.- Opening the leading-edge slots appeared to have little effect on tumbling. When the slots were opened and spoilers mounted on the inboard part of the wing were fully extended, the model sometimes continued to tumble when launched with initial negative rotation with the stick back and sometimes stopped tumbling and went into an oscillatory dive. When the slots were open and the rudders on one wing were extended, similar results were obtained.

The preceding results indicate that the tumbling tendencies of the model were most improved by moving the center of gravity forward. Opening the rudders on one or both wings appeared to be somewhat beneficial. Deflecting the pitch flaps up and moving the stick full back diminished the tendency of the model to tumble with negative rotation, and putting the landing flaps and pitch flaps down and moving the stick forward diminished the tendency of the model to tumble with positive rotation.

CONTROL FORCES

All results presented herein indicate the effectiveness of controls without regard to the forces applied. Because of the large size of the airplane and the high rates of descent in spins and tumbles, it is probable that the control forces will be high. The actual loads developed during the maneuvers may also be high and may exceed the structural strength of the airplane.

CONCLUSIONS

The model results indicate the following spin and tumbling characteristics for the XB-35 airplane:

1. Spin characteristics:

(a) When the rudders are with the spin, the airplane in the normal loading, clean condition will spin only when the wheel is with the spin and the stick is neutral or full back. It will not be possible to effect recovery from these spins by reversing the rudder. Inasmuch as the airplane will spin for most combinations of stick-wheel position when the rudders are against the spin, the conventional recovery technique of reversing the rudder and then moving the stick forward will not effect recoveries, and it appears advisable to keep the rudders with the spin.

(b) Increasing the longitudinal loading will cause the airplane to spin for more control positions than with normal loading. Recovery by reversing the rudders will be unsatisfactory.

(c) Moving the center of gravity 7.5 percent of the mean aerodynamic chord forward will be somewhat beneficial.

(d) Moving the center of gravity rearward will cause the airplane to spin for more stick-wheel positions when the rudder is with the spin than for normal loading but will reduce the number of stick-wheel positions for which rudder-against spins will be obtained.

(e) Extending or retracting mass along the wing or retracting mass longitudinally will have little effect on spin characteristics.

(f) With the airplane in the landing condition, the spin characteristics will be generally similar to those for the clean condition.

(g) For best recovery, the rudders should be kept full with the spin, the stick should be put full forward, and the wheel should be put full against the spin. Recoveries thus obtained will be rapid.

2. Tumbling characteristics:

(a) In the normal loading, clean condition, the airplane may go into a tumble from a whip stall. Even if it does not start tumbling, it may experience extreme oscillations in pitch. These oscillations will be only lightly damped.

(b) Moving the center of gravity forward appreciably will diminish the tendency of the airplane to tumble.

(c) When the landing and pitch flaps are down and the stick is forward the airplane will not tumble with positive rotation, and when the pitch flaps are up and the stick is back the airplane will not tumble with negative rotation.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 20, 1944.

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TABLE I.- DIMENSIONAL CHARACTERISTICS

OF NORTHROP XB-35 AIRPLANE

Wing span, ft	172
Length over all, ft	50.9
Normal weight, lb	155,000
Normal center-of-gravity location, percent M.A.C.	27.5
Wing:	
Area, sq ft	4020
Section - root	NACA 65,3-019
Section - tip	NACA 65,3-018
Wing twist, root to tip, deg	4
Aspect ratio	7.36
Sweepback of leading edge of wing, deg	25.8
Dihedral at 25 percent chord line, deg	2
Mean aerodynamic chord, in.	315
Leading edge M.A.C. aft leading-edge root chord, in.	210
Flap chord, percent c	21.4
Elevons:	
Chord, percent c	17.8
Area aft hinge line, percent wing area	6.8
Span, percent b/2	40.0
Distance from normal center of gravity to center of elevon hinge line, in.	202.2
Pitch flaps:	
Total area, sq ft	160
Pitch-flap area, percent of wing area	4.0
Area aft of hinge line, sq ft	160
Distance from normal center of gravity to center of pitch-flap hinge line, in.	254.0
Span, percent b/2	21.2
Rudders:	
Total area split rudders, sq ft	120
Distance from normal center of gravity to center of rudder hinge line, in.	264.6
Span, percent b/2	21.2
Area, percent wing area	3.0

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TABLE II.- CONDITIONS OF NORTHROP XB-35 AIRPLANE

INVESTIGATED IN FREE-SPINNING TUNNEL

Number	Condition	Loading (a)	Type test	Rudder settings (deg)	Pitch-flap settings (deg)	Slots	Spoilers	Data on
1	Clean	A	Spin	±60	0	Closed	None	Chart 1
2						Open		Chart 2
3					Down 15	Closed		Chart 3
4					Up 30			None
5		B			0			Chart 4
6		C						Chart 5
7		D						Chart 6
8		E						Chart 7
9		F						None
10		G						None
11		H						None
12	Landing	A			Up 30	Open		Chart 8
13						Closed		Chart 9
14	Clean		Tumbling[b]	0	0			Table III
15			Tumbling[c]					Table IV
16		C						
17		A		Both rudders ±60				
18				±60				
19				0	Up 30			
20					Down 15			
21	Landing flaps deflected				0			
22				±60				
23	Spoilers installed			0			Outboard	
24	Clean					Open	None	
25	Spoilers installed						Inboard	
26	Clean			±60			None	

[a]Loadings:

- A Normal.
- B I_Y and I_Z increased by 30 percent of I_Y.
- C Center of gravity moved forward 7.5 percent of mean aerodynamic chord.
- D Center of gravity moved rearward 5.8 percent of mean aerodynamic chord.
- E Center of gravity moved rearward 11.6 percent of mean aerodynamic chord.
- F I_X and I_Z increased by 30 percent of I_X.
- G I_X and I_Z decreased by 10 percent of I_X.
- H I_Y and I_Z decreased by 30 percent of I_Y.

[b]Model released without rotation in a nose-up attitude simulating a whip stall.

[c]Model launched with initial pitching rotation.

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TABLE III.- TUMBLING TESTS

[Model released in a nose-up attitude, simulating a whip stall]

Model loading	Model condition	Control position during tests				Tunnel airspeed, fps, full scale	Behavior of model
		Rudders	Control column		Pitch flaps		
			Longitudinally	Laterally			
Normal	Clean	Neutral	Back	Neutral	Neutral	111	Oscillated in pitch through almost $\pm 180^{\circ}$, measured from the nose-down attitude
				Left			
				Right			
			Neutral				
				Neutral			
				Left			
			Forward				
				Neutral			
				Right			Occasionally tumbled
				Left		172	

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TABLE IV.- TUMBLING TESTS

[Model given initial pitching rotation about lateral axis. Tunnel airspeed for all tests was 172 fps, full scale.]

Model loading	Model condition	Control positions during tests				Direction of initial pitching rotation	Behavior of model
		Rudders	Control column		Pitch flaps		
			Longitudinally	Laterally			
Normal	Clean	Neutral	Back	Neutral	Neutral	Positive	Continued to tumble
				Right			
				Left			
			Neutral				
				Neutral			
				Right			
			Forward				
				Neutral			
				Left			
						Negative	
				Neutral			
				Right			
			Neutral				
				Neutral			
				Left			
			Back				
				Neutral			
				Right			
Center of gravity forward 7.5 percent M.A.C				Neutral			Stopped tumbling, went into dive with oscillations in pitch
				Left			
			Neutral				
				Neutral			
			Forward				
				Left			
						Positive	
				Neutral			
			Neutral				
				Left			
			Back	Neutral			
				Left			Would tumble when launched with sufficient translational velocity
Normal		Both open		Neutral			Continued to tumble
				Right			
			Neutral				
				Neutral			

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TABLE IV - Continued

Model loading	Model condition	Control positions during tests: Rudders	Control column: Longitudinally	Control column: Laterally	Pitch flaps	Direction of initial pitching rotation	Behavior of model
Normal	Clean	Both open	Forward	Neutral	Neutral	Positive	Continued to tumble
				Right			
						Negative	
				Neutral			
			Neutral				
				Right			
			Back				Stopped tumbling, went into dive with oscillations in pitch
				Neutral			Stopped tumbling, went into positive tumble
		Right open					Sometimes stopped tumbling, went into positive tumble. Sometimes continued tumbling
				Left			
				Right			Continued to tumble
						Positive	
				Neutral			
				Left			
		Neutral			Up 30°		
				Neutral			
			Neutral				
				Left			
			Forward				
				Neutral			
						Negative	
				Left			
			Neutral				
				Neutral			
			Back				Stopped tumbling, went into dive with oscillations in pitch
				Left			Sometimes stopped. Sometimes stopped and went into positive tumble
					Down 15°		Continued to tumble
				Neutral			
			Neutral				
				Left			
			Forward				
				Neutral			

TABLE IV - Concluded

Model loading	Model condition	Control positions during tests: Rudders	Control column: Longitudinally	Control column: Laterally	Pitch flaps	Direction of initial pitching rotation	Behavior of model
Normal	Clean	Neutral	Forward	Neutral	Down 15°	Positive	Continued to tumble
				Left			
			Neutral				
				Neutral			
			Back				
				Left			
	Landing flaps down 60°			Neutral	Neutral		
			Neutral				
			Forward				Sometimes stopped tumbling, sometimes continued tumbling
						Negative	Continued to tumble
			Back				
					Down 15°	Positive	
			Neutral				Stopped tumbling, went into dive with oscillations in pitch
			Forward				
		Right open			Neutral		
			Neutral				Sometimes stopped tumbling, sometimes continued tumbling
				Right			
				Left			
	Outboard spoilers open	Neutral	Forward	Neutral			Continued to tumble
			Neutral				
						Negative	
			Back				
	Slots open						
			Forward			Positive	
	Slots and center spoilers open						
			Back			Negative	Sometimes stopped tumbling, sometimes continued tumbling
	Slots open	Left open					Stopped tumbling, went into dive with oscillations in pitch
			Forward			Positive	Continued to tumble

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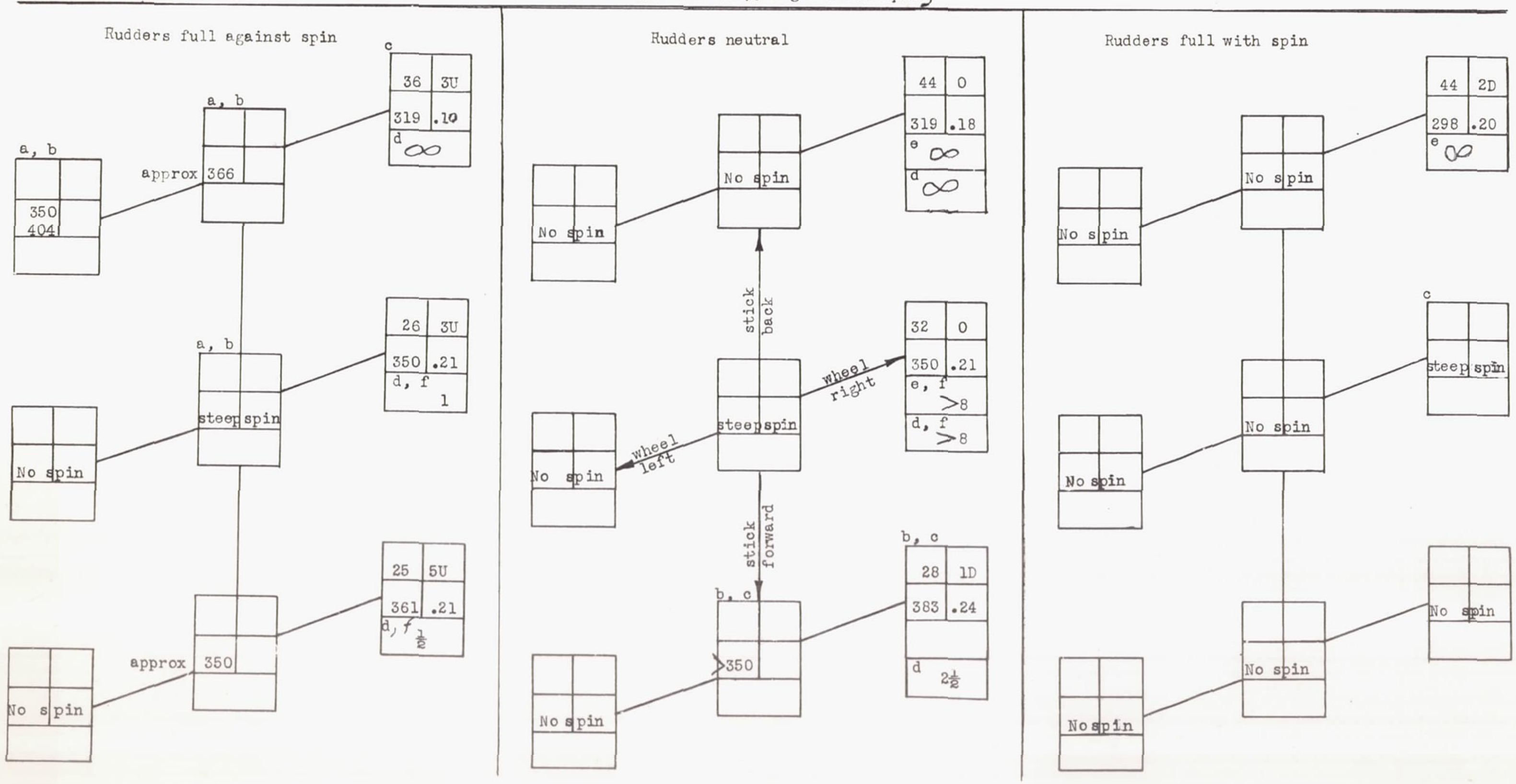
CHART 1. - EFFECT OF CONTROLS ON SPIN CHARACTERISTICS OF XB-35 MODEL WITH SLOTS CLOSED

[Normal loading; landing gear retracted; landing and pitch flaps neutral; recovery as indicated (steady-spin data presented for, and recovery attempted from, spins with initial rudder setting indicated); right erect spins]



[a]Spins with large radius.
[b]Wanders.
[c]Oscillation in pitch.
[d]Recovery attempted by moving rudder to full with the spin.
[e]Recovery attempted by moving rudder to full against the spin.
[f]Visual observation.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
∞ means model would not recover

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

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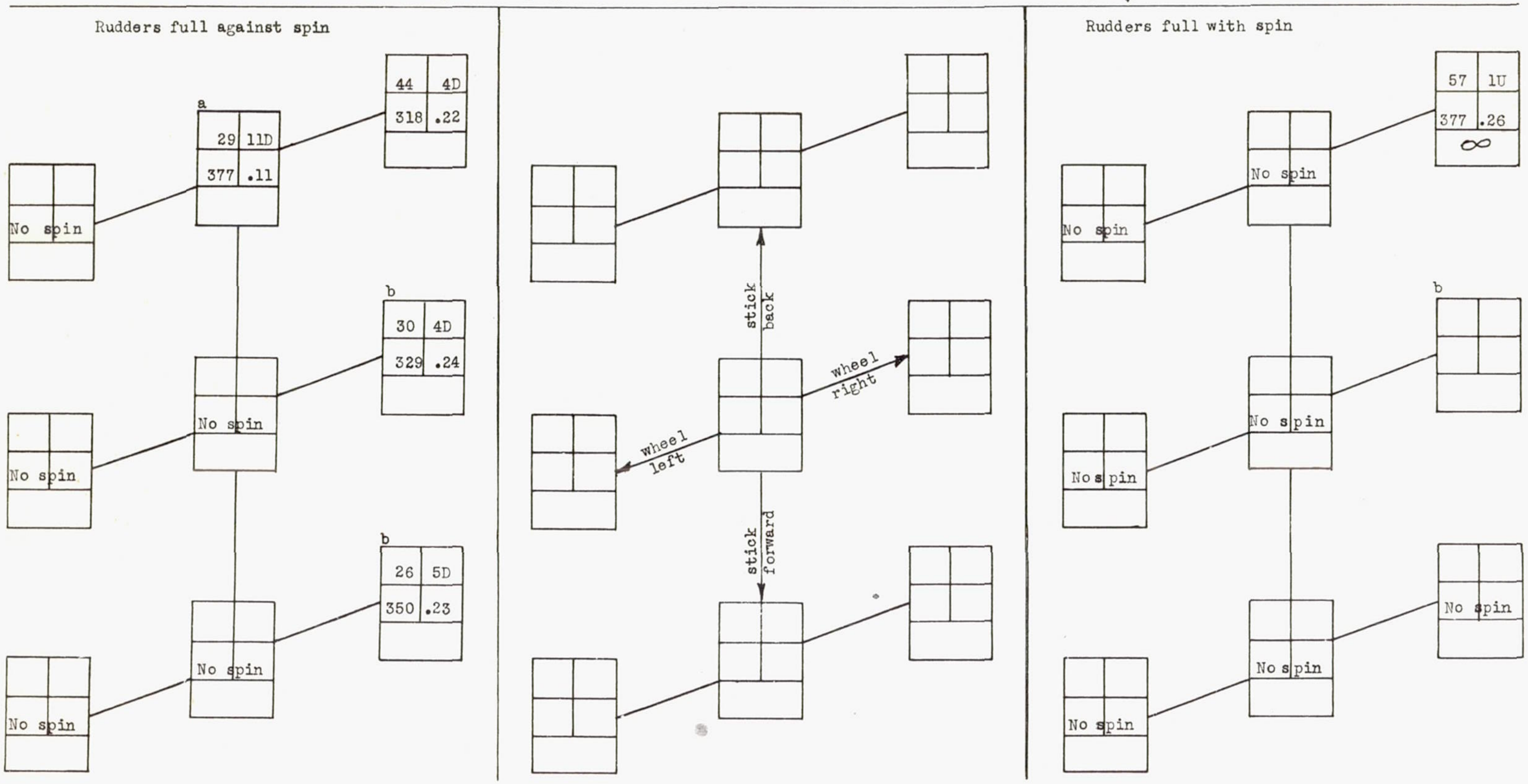
CHART 2. - EFFECT OF CONTROLS ON SPIN CHARACTERISTICS OF XB-35 MODEL WITH SLOTS OPEN

[Normal loading; landing gear retracted; landing and pitch flaps neutral; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from, spins with initial rudder setting indicated); right erect spins]



[a]Spins with large radius.
[b]Oscillatory spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
∞ means model would not recover

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

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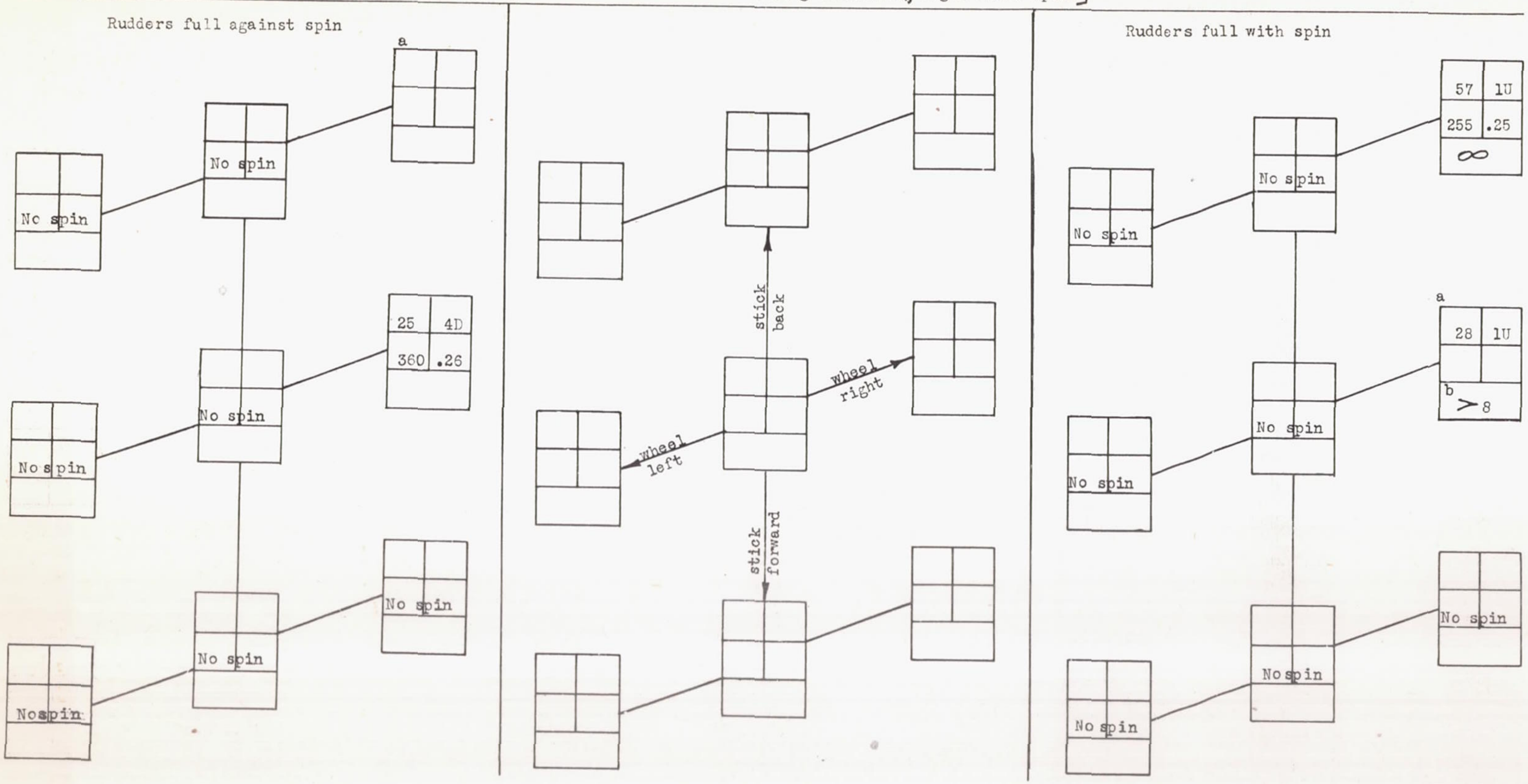
CHART 3[illegible]. - EFFECT OF CONTROLS ON THE SPIN CHARACTERISTICS OF THE XB-35 MODEL WITH BOTH PITCH FLAPS DEFLECTED DOWN 15 DEGREES

[Normal loading; landing gear retracted; landing flaps neutral; slots closed; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from spins with initial rudder setting indicated); right erect spins]



[a]Oscillates in pitch.
[b]Visual observation.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
∞ means that model would not recover

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

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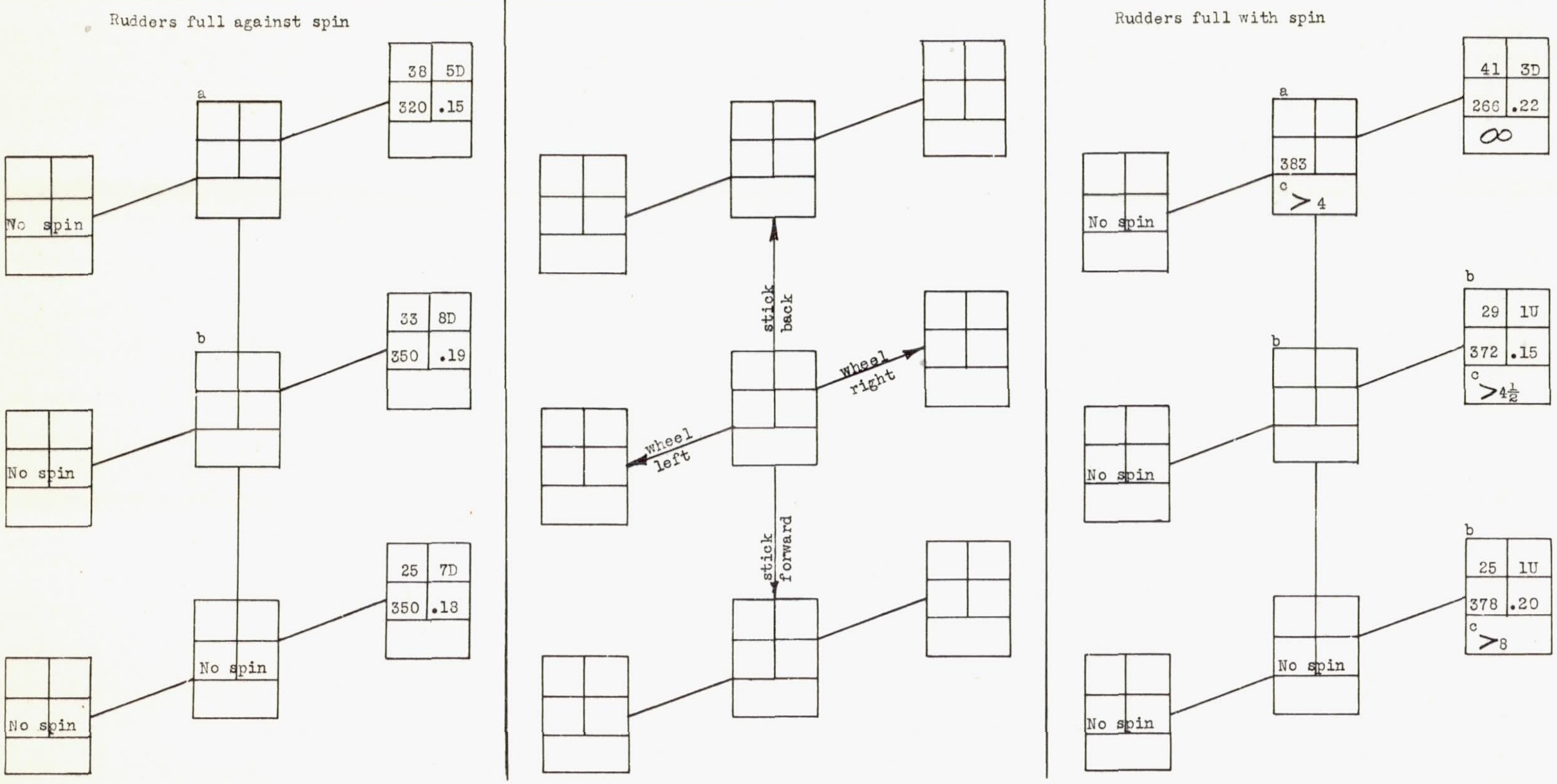
CHART 4. - EFFECT OF CONTROLS ON SPIN CHARACTERISTICS OF XB-35 MODEL WITH MASS EXTENDED LONGITUDINALLY

[I_Y and I_Z increased by 30 percent of I_Y from normal; landing gear retracted; landing and pitch flaps neutral; slots closed; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from, spins with initial rudder setting indicated); right erect spins]



[a]Spins with large radius.
[b]Oscillatory spin.
[c]Visual observation.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
∞ means model would not recover

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

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CHART 5. - EFFECT OF CONTROLS ON THE SPIN CHARACTERISTICS OF XB-35 MODEL WITH THE CENTER OF GRAVITY MOVED FORWARD OF NORMAL

[Center of gravity 7.5 percent M.A.C. forward of normal; landing gear retracted; landing and pitch flaps neutral; slots closed; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from, spins with initial rudder setting indicated); right erect spins]

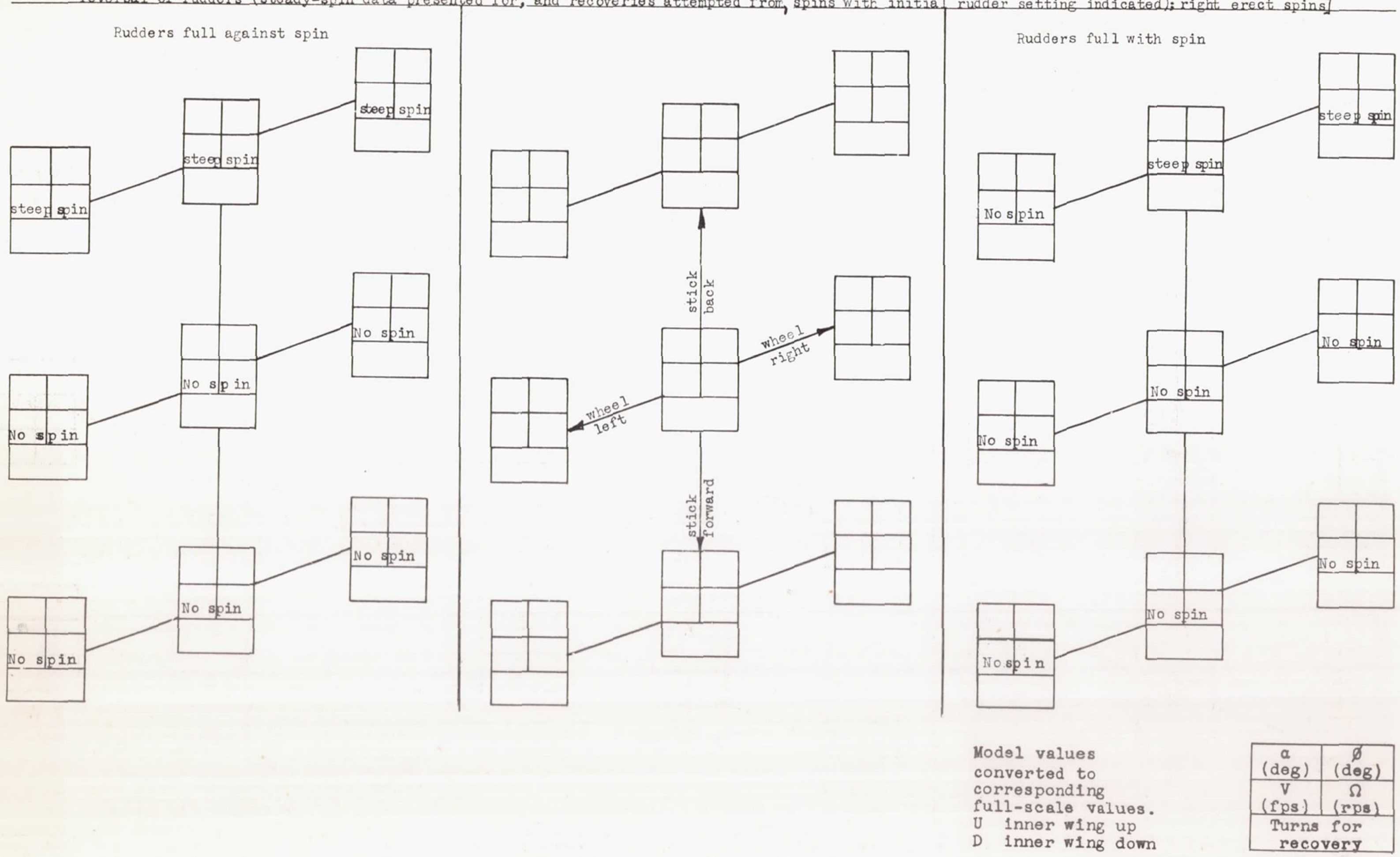
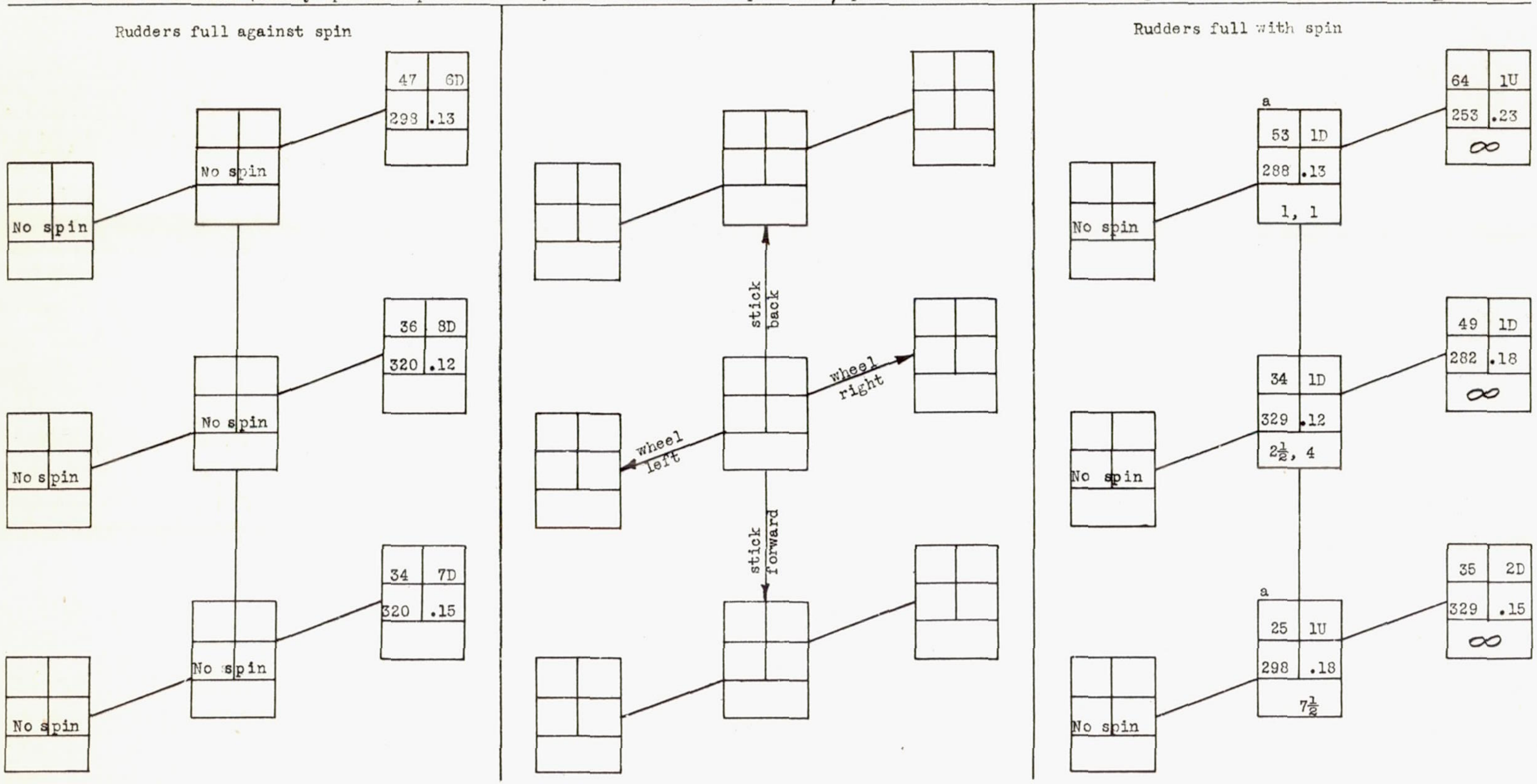


CHART 6. - EFFECT OF CONTROLS ON THE SPIN CHARACTERISTICS OF THE XB-35 MODEL WITH THE CENTER OF GRAVITY MOVED REARWARD OF NORMAL

[Center of gravity moved 5.8 percent M.A.C. rearward of normal; landing gear retracted; landing and pitch flaps neutral; slots closed; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from, spins with initial rudder setting indicated); right erect spins]



[a]Occasionally oscillated out of spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
∞ means model would not recover

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

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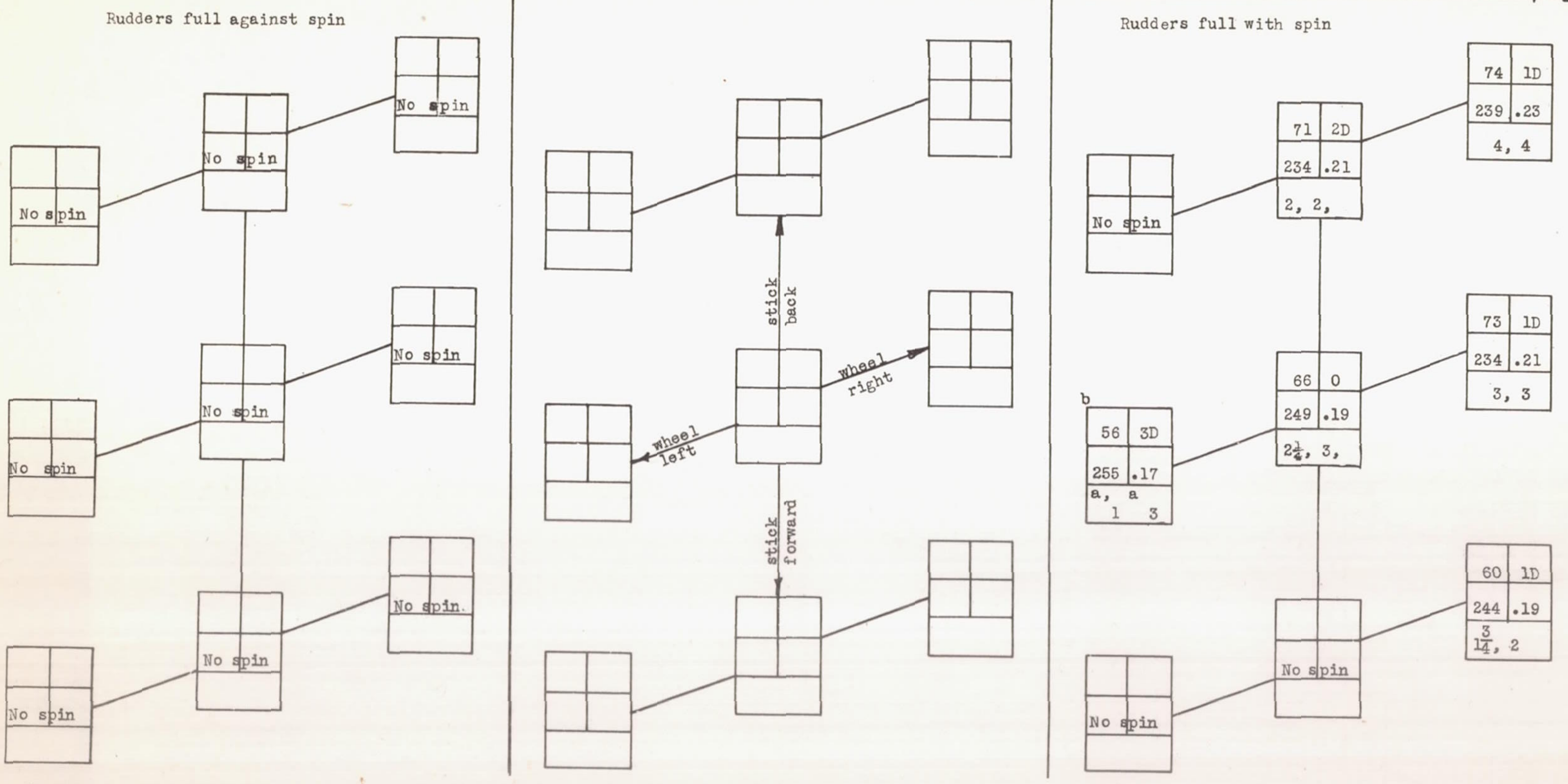
CHART 7. - EFFECT OF CONTROLS ON THE SPIN CHARACTERISTICS OF THE XB-35 MODEL WITH THE CENTER OF GRAVITY MOVED REARWARD OF NORMAL

[Center of gravity moved 11.6 percent M.A.C. rearward of normal; landing gear retracted; landing and pitch flaps neutral; slots closed; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from, spins with initial rudder setting indicated); right erect spins]



[a] Visual observation.
[b] Oscillatory.

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

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

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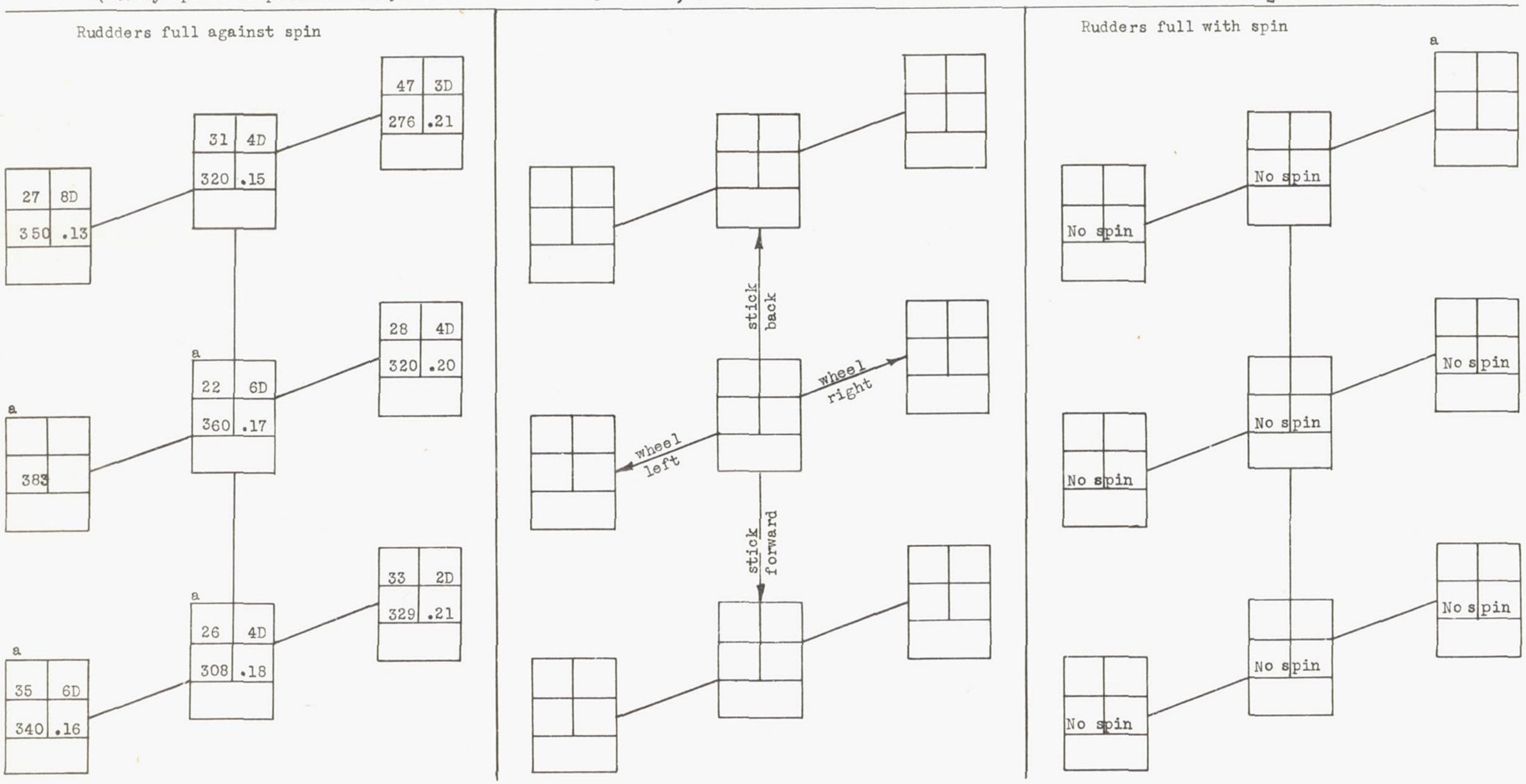
CHART 8. - EFFECT OF CONTROLS ON THE SPIN CHARACTERISTICS OF XB-35 MODEL IN THE LANDING CONDITION

[Normal loading; landing gear extended; landing flaps down 60 degrees; pitch flaps up 30 degrees; slots open; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from, spins with initial rudder setting indicated); right erect spins]



[a] Oscillatory.

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

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

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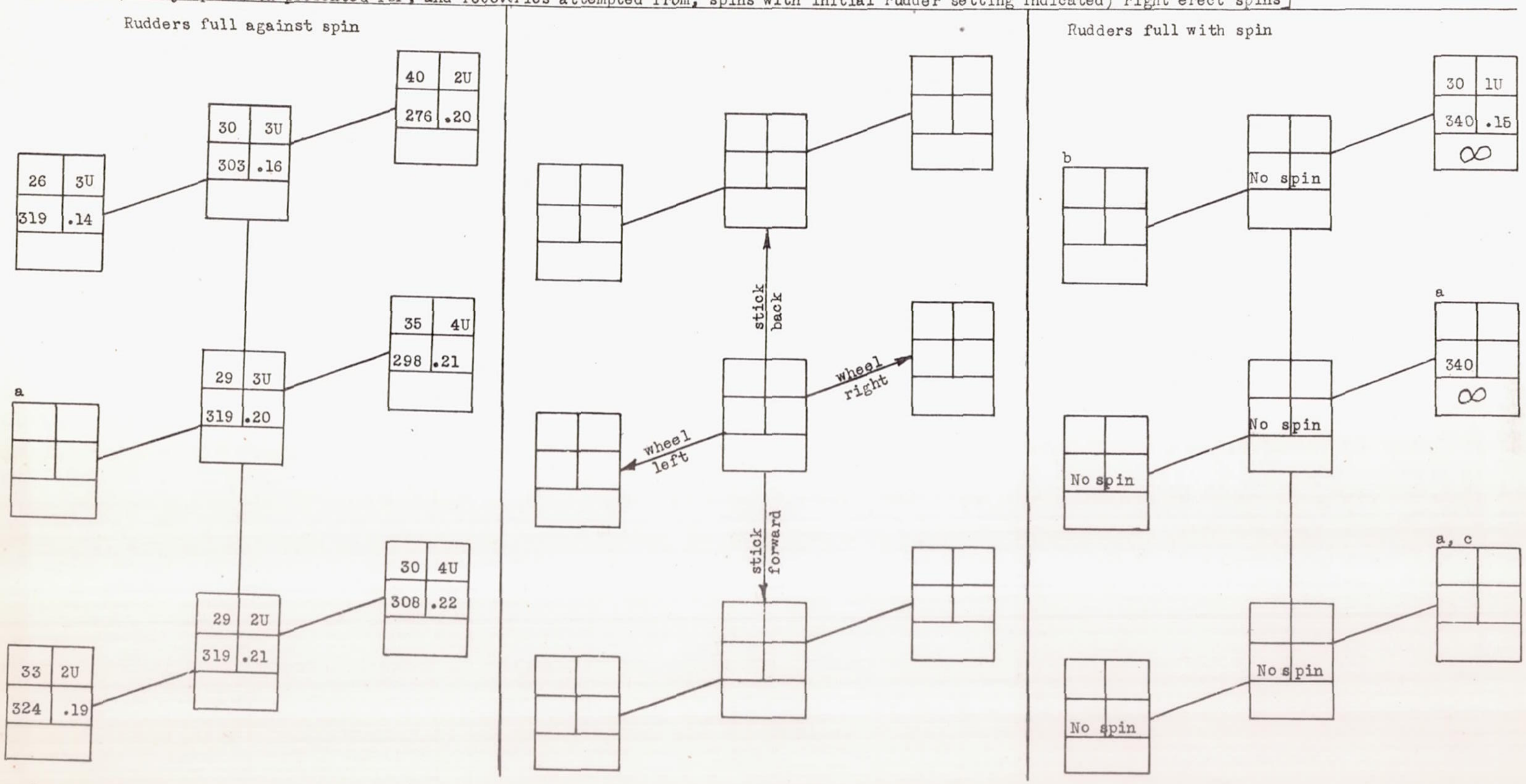
CHART 9. - EFFECT OF CONTROLS ON THE SPIN CHARACTERISTICS OF XB-35 MODEL IN LANDING CONDITION WITH SLOTS CLOSED

[Normal loading; landing gear extended; landing flaps down 60 degrees; pitch flaps up 30 degrees; recovery by rapid full reversal of rudders (steady-spin data presented for, and recoveries attempted from, spins with initial rudder setting indicated) right erect spins]



[a]Oscillatory.
[b]Increasing radius, may not spin.
[c]Spins with large radius.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down
∞ means that model would not recover

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

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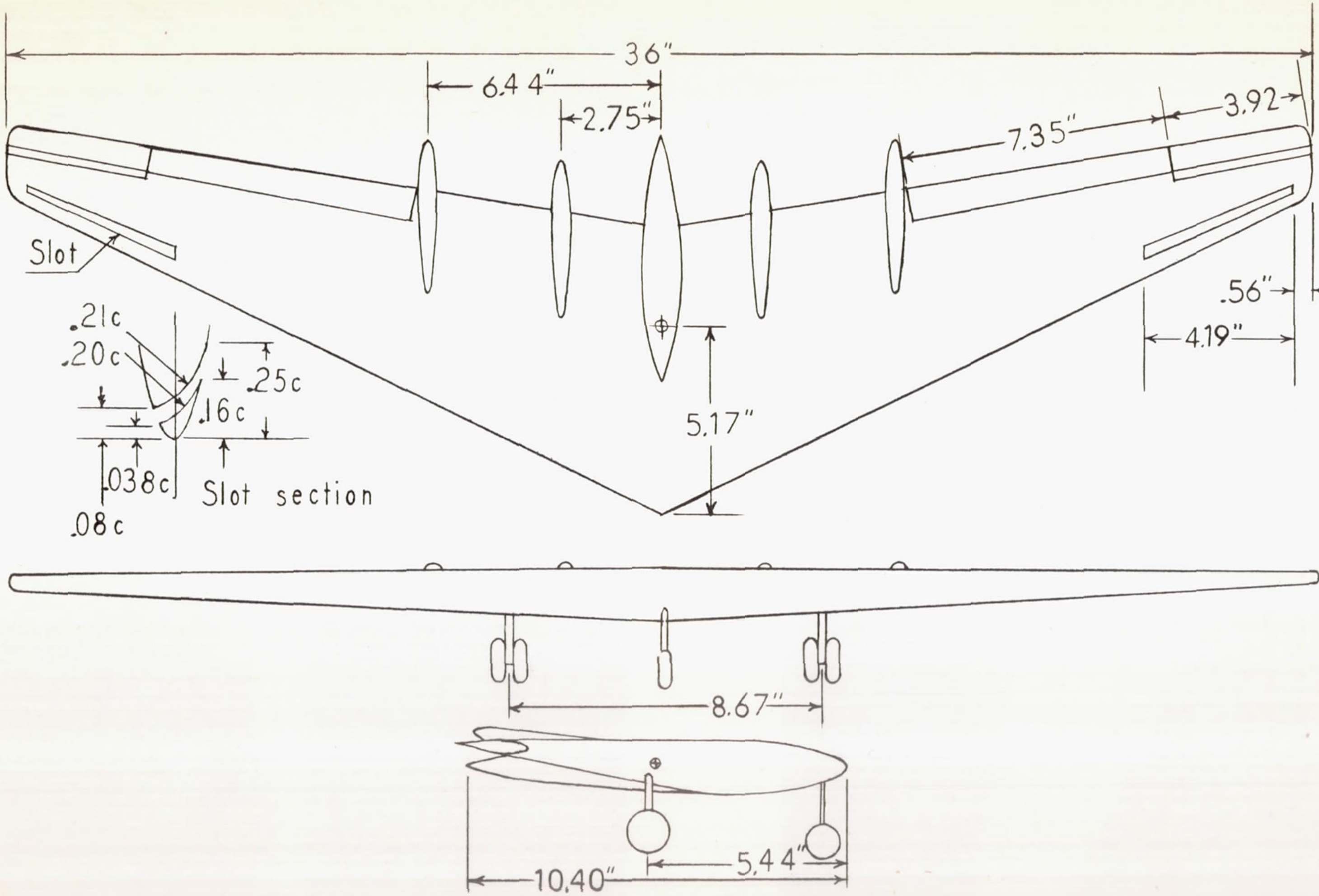

Figure 1.- Drawing of 1/57.33-scale model of the Northrop XB-35 airplane. Model is shown with landing gear extended and slots open.

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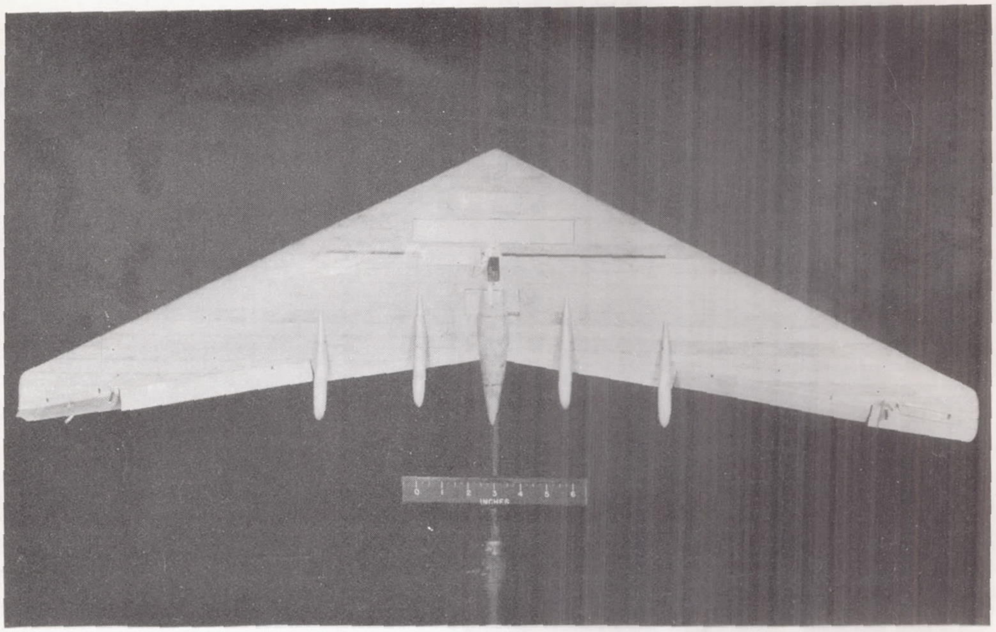

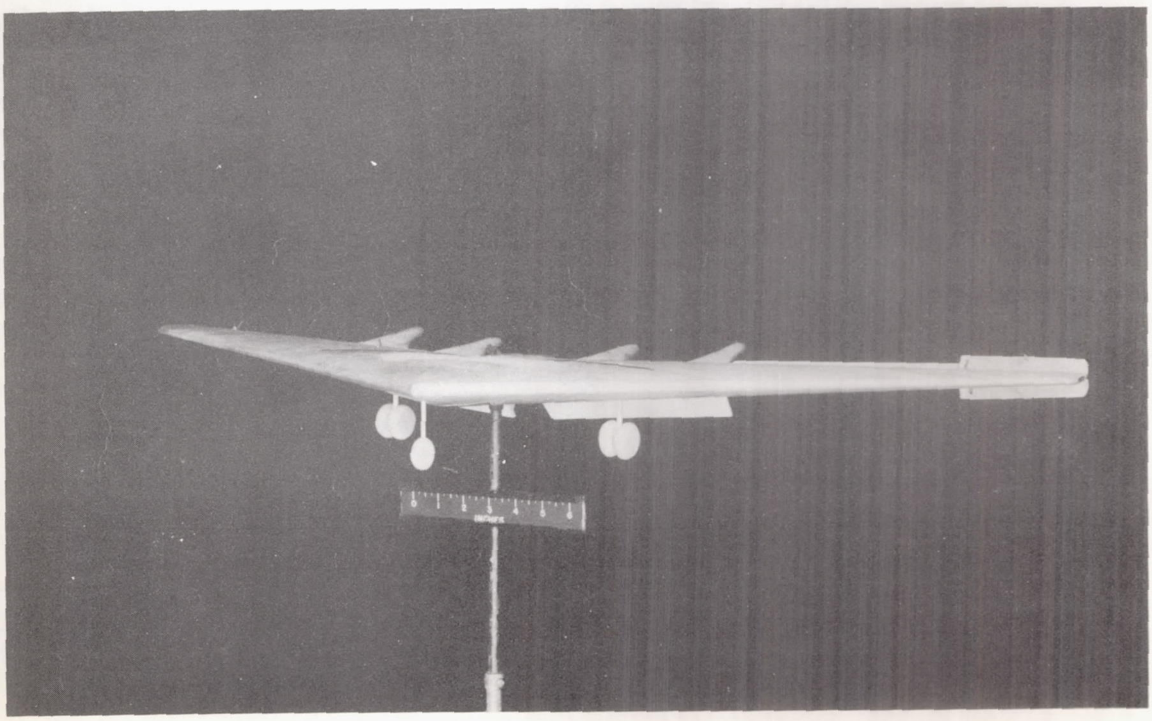

Figure 2.- $\frac{1}{57.33}$-scale model of the Northrop XB-35 airplane.

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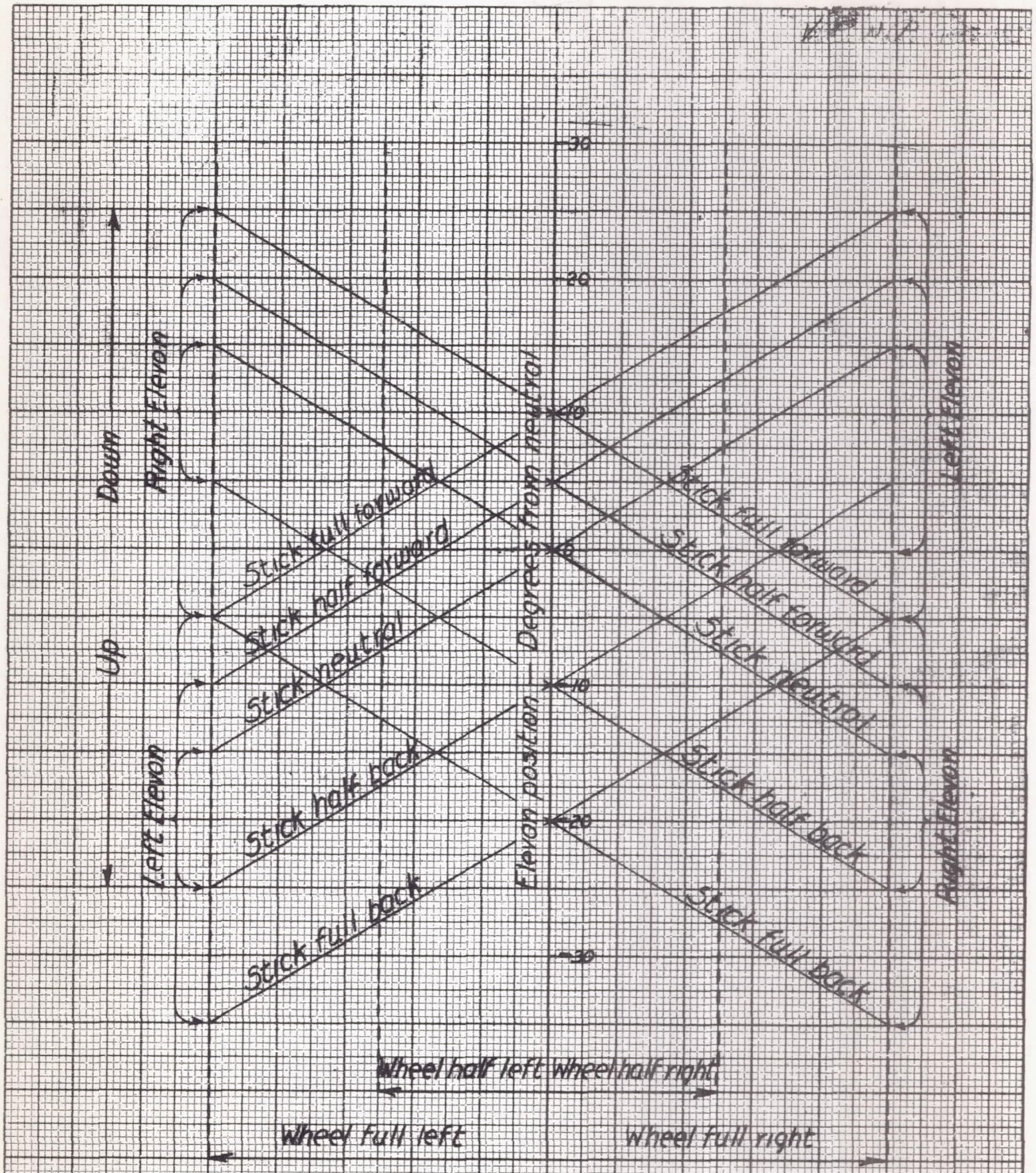

FIGURE 3 - Elevon deflections used on XB-35 model for various combinations of stick and wheel positions.

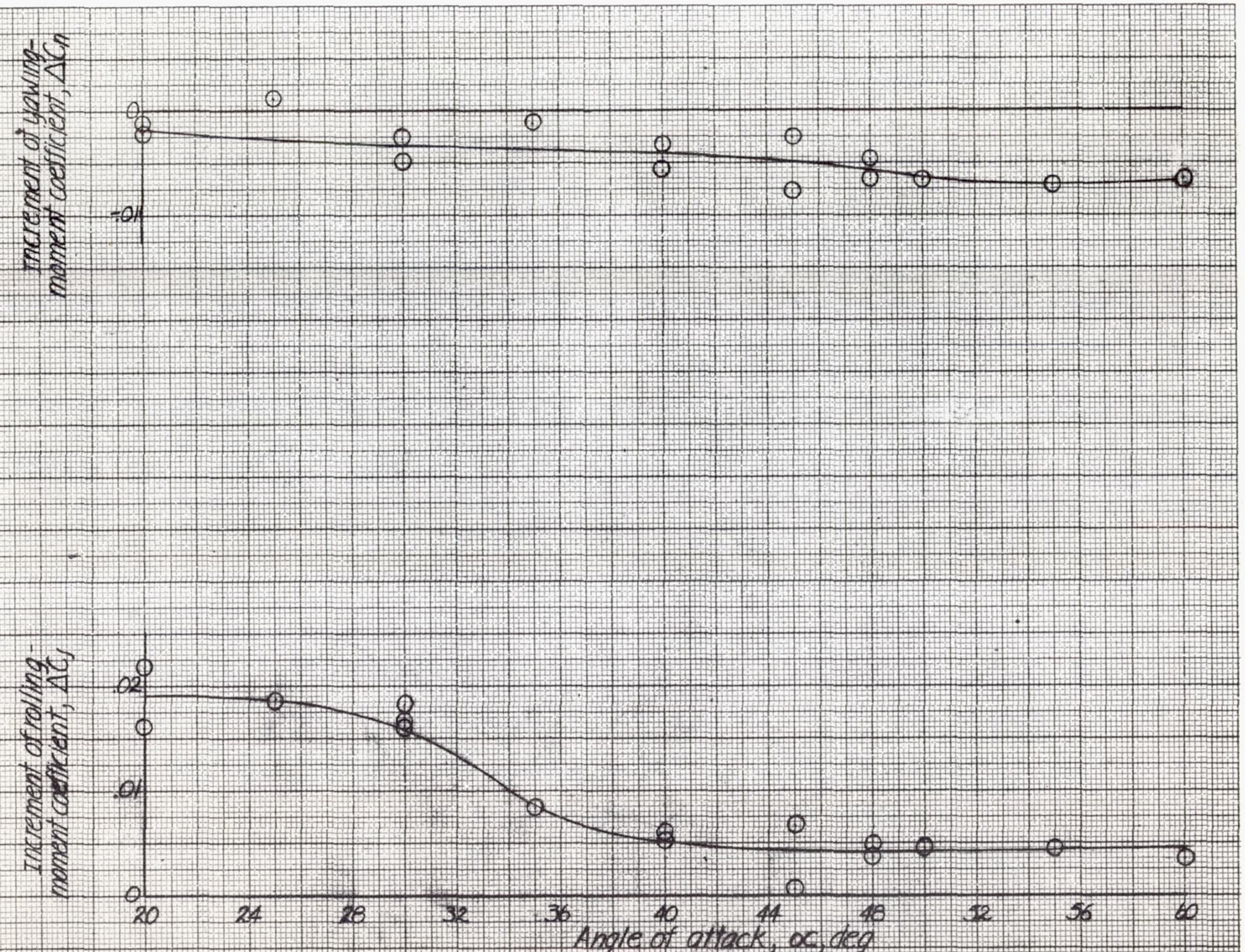

FIGURE 4- Increments of yawing-and rolling-moment coefficients due to rudders as a function of angle of attack. Rudders on left wing tip fully extended; rudders on right tip neutral; q=4.274