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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

SUPPLEMENTARY INVESTIGATION IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL OF THE SPIN AND RECOVERY CHARACTERISTICS OF A 0.057-SCALE MODEL OF THE CHANCE VOUGHT XF7U-1 AIRPLANE

TED NO. NACA DE 311

By Theodore Berman

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

An investigation has been conducted in the Langley 20-foot free-spinning tunnel to determine the effects of decreasing the rudder deflection, of decreasing the rudder span, and of differential rudder movements on the spin and recovery characteristics of a 0.057-scale model of the Chance Vought XF7U-1 airplane.

The results indicated that decreasing the rudder span or the rudder deflections, individually or jointly, did not seriously alter the spin or recovery characteristics of the model, and recovery by normal use of controls (full rapid rudder reversal followed 1/2 to 1 turn later by movement of the stick forward of neutral) remained satisfactory. Linking the original rudders so that the inboard rudder moves from full with the spin to neutral while the outboard rudder moves from neutral to full against the spin will also result in satisfactory spin and recovery characteristics. Calculations of rudder-pedal forces for recovery showed that the expected forces would probably be within the capabilities of a pilot but that it would be advisable to install some type of boost in the control system to insure easy and rapid movement of the rudders.

INTRODUCTION

A letter from the contractor reported that in the course of flight testing the Chance Vought XF7U-1 airplane, it was found that the variation of yaw angle with rudder angle was greater than desirable. Several remedies were proposed for this condition, including a reduction in the maximum rudder deflection from ±25° to ±15°, reducing the rudder span by fixing the portion of the rudder below the wing at neutral, or linking the original rudders to move differentially. In addition, horn balances have been incorporated on the rudders. The Bureau of Aeronautics, Department of the Navy, requested that the NACA determine the effect of these proposed changes on the spin and recovery characteristics of the XF7U-1 airplane. The spin and recovery characteristics of the XF7U-1 in the original configuration were reported in reference 1.

Tests were made with the original rudders with deflections of ±25° and ±15°, with the reduced-span rudders with deflections of ±25° and ±15°, and with the original rudders differentially linked with maximum deflections of 25° and 15°. The model was reballasted to correspond with the latest information concerning weight, center-of-gravity location, and moments of inertia, the new loading being quite similar to that of the original tests.

SYMBOLS

b	wing span, feet
S	wing area, square feet
c	wing or elevator chord at any station along the span
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	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 root chord line to mean aerodynamic chord (positive when center of gravity is below root chord line)
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^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, slugs per cubic foot

μ relative density of airplane $\left(\frac{m}{\rho S b}\right)$

α angle between root chord line and vertical (approximately equal to absolute value of angle of attack at 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 flight path and vertical, degrees (For the tests of this model, the average absolute value of the helix angle was approximately 3°.)

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

APPARATUS AND METHODS

Model

A 0.057-scale model of the XF7U-1 previously tested at Langley was available and was therefore used for the current investigation. A three-view drawing of the model as tested with the original rudders is given in figure 1. A sketch showing the original and shortened rudders is given in figure 2. The dimensional characteristics of the airplane are presented in table I. The model was not altered to incorporate the horn balances previously mentioned as this change was expected to have little effect on the spin and recovery characteristics of the model.

The model was ballasted with lead weights to obtain dynamic similarity to the airplane at an altitude of 15,000 feet (ρ = 0.001496 slug/cubic foot), and a remote-control mechanism was installed in the model to actuate the controls for recovery tests. Sufficient moments were exerted on the control surfaces during recovery tests to insure their full and rapid movements.

Wind Tunnel and Testing Technique

The model tests were performed in the Langley 20-foot free-spinning tunnel in a manner similar to that described in reference 1. The testing procedure and the technique for obtaining and converting the data to full-scale values were the same as those used in reference 1.

PRECISION

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

α, degrees	± 1
φ, degrees	± 1
V, percent	± 5
Ω, percent	± 2
Turns for recovery:	
From films	$\pm\frac{1}{4}$
Visual observation	$\pm\frac{1}{2}$

The preceding limits may have been exceeded for certain spins in which it was difficult to control 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 spin results of airplanes and corresponding models (reference 2) indicates that spin-tunnel results are not always in complete agreement with full-scale spin results. This comparison indicated that approximately 80 percent of the model recovery tests predicted satisfactorily the corresponding airplane turns for recovery, approximately 10 percent underestimated, and approximately 10 percent overestimated them.

Because of the impracticability of exact ballasting of the model and because of small inadvertent changes during testing, the measured weight and mass distribution of the model varied from the true scaled-down values by the following amounts:

Weight, percent	0 high to 1 low
Center-of-gravity location, percent $\bar{c}$	1 aft to 0
Moments of inertia:	
I_X, percent	3 high to 1 high
I_Y, percent	5 high to 3 low
I_Z, percent	6 high to 1 low

The limits of accuracy of the measurements of the mass characteristics are believed to be:

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

The controls were set with an accuracy of ±1°.

Test Conditions

The mass characteristics and inertia parameters of the airplane and of the model as tested are shown in table II. The inertia parameters of the XF7U-1 airplane and model are plotted in figure 3 which can be used as an aid in predicting the effects of controls on the spin and recovery characteristics as discussed in reference 3.

The maximum control deflections used for the current tests were:

Rudders, degrees	25 right, 25 left 15 right, 15 left
Ailavators, degrees:	
As elevators	30 up, 20 down
As ailerons	15 up, 15 down

Intermediate control deflections used were:

Rudders, two-thirds deflected, degrees	$16\frac{2}{3}$ 10
Ailavators, degrees:	
Deflected as elevator, stick two-thirds back	20
Deflected as elevator, stick one-half back	15
Deflected as elevator, stick one-third back	10
Deflected as ailerons, stick one-third left	±5
Deflected as ailerons, stick two-thirds left	±10

The differential rudder deflections used were:

Full right rudder pedal, degrees . .	Right rudder 25 right, left rudder 0 Right rudder 15 right, left rudder 0
Full left rudder pedal, degrees . .	Right rudder 0, left rudder 25 left Right rudder 0, left rudder 15 left

When the rudders were moved differentially, the inboard rudder (right rudder in right spin) moved from the position with the spin to neutral while the outboard rudder moved from neutral to the position against the spin.

The differential deflections of the ailavators resulting from lateral stick displacements are added algebraically to the ailavator deflections resulting from longitudinal stick displacements.

For convenience in this report, longitudinal movement of the stick will be referred to as elevator deflection, and lateral movement will be referred to as aileron deflection.

RESULTS AND DISCUSSION

The results of spin tests of the model are presented in charts 1 to 6. The model data are presented in terms of full-scale values for the airplane at a test altitude of 15,000 feet. Because right and left spins were generally similar, data for right spins only are arbitrarily presented.

Original Rudders and Original Rudder Deflections

Model spin data obtained with the original rudders installed with deflections of $\pm 25^{\circ}$ are presented in chart 1. These results were compared with the original results presented in reference 1 and were found to be generally similar.

Original Rudders and Reduced Rudder Deflections

Chart 2 contains data obtained with the original rudders but with the deflections reduced from $\pm 25^{\circ}$ to $\pm 15^{\circ}$. The results show that the spins became slightly steeper as shown by the criterion spin (ailerons 1/3 against, elevator 2/3 up), the spin with elevator full up and ailerons full against, and the spin at normal spinning configuration (ailerons neutral, elevator full up). The data also show that the recovery characteristics for the model in this configuration were satisfactory by rudder reversal and that recoveries from the criterion spin and from the spin at normal spinning configuration were satisfactory even when the rudders were only neutralized in the recovery attempt. It was noted, however, that recoveries by rudder reversal became slower as the elevator setting approached neutral from the up position, indicating that in a recovery attempt in the airplane, care should be exercised to avoid premature movement of the elevator down. Setting the ailerons against the spin when the elevator was neutral or down led to very flat spins from which recovery could not be obtained by full rudder reversal. This result shows again, as in reference 1, that moving the ailerons against the spin may be very detrimental to spin recovery.

Reduced-Span Rudders and Original Rudder Deflections

Results presented in chart 3 show the effect of reducing the rudder span while retaining the original rudder deflections. Recoveries from the criterion spin and from the spin at normal configuration for spinning were satisfactory. The results again indicated that premature movement of the elevator down would adversely affect recoveries.

Reduced-Span Rudders and Reduced Rudder Deflections

Data obtained with the reduced-span rudders and the reduced rudder deflections are presented in chart 4. These data show that this configuration with the ailerons 1/3 against and the elevator 1/3 up, resulted in steeper spins than any of the previously tested configurations indicating that the reduced-span rudders and the reduced deflections produced a smaller pro-spin moment maintaining the spin than the full-span rudders and the original deflections. Recoveries were satisfactory by either rudder reversal or rudder neutralization.

Differential Rudder Movement

Test results obtained when the original rudders were linked to move differentially are shown in charts 5 and 6. Recoveries were satisfactory when the inboard rudder moved from the position with the spin to neutral while the outboard rudder was going from neutral to a position against the spin. When the maximum rudder deflection was 15° there was not enough pro-spin moment to maintain the spin for most control configurations. The adverse effect of setting the ailerons full against the spin, however, was still obtained.

Recommended Recovery Technique

On the basis of the test results, the use of the following spin-recovery technique is recommended for all loadings:

The stick should be held full back and laterally neutral. The rudders should be reversed fully and rapidly followed, 1/2 to 1 turn later, by movement of the stick briskly forward of neutral while keeping it laterally neutral. Care should be exercised to avoid premature movement of the stick forward and also to avoid excessive rates of acceleration in the ensuing recovery dive.

Control Forces

The discussion of the results so far has been based on control effectiveness alone without regard to the forces required to reverse the controls. As previously mentioned, sufficient force was applied to the controls to move them fully and rapidly for all tests. Sufficient force must be applied to the airplane controls to move them in a similar manner in order for the model and airplane results to be comparable.

Concern has been expressed by the contractor regarding rudder forces required for recovery. Model test data indicate two possible types of spin for the airplane. The first was at a moderate angle of attack and the second at a steeper angle of attack such that the model descended at a rate greater than the tunnel could accommodate. Data reported in reference 1 indicated that the forces required for recovery by rudder reversal from the spin at the moderate angle of attack would be heavy but probably within the capabilities of the pilot. It was felt that in the steeper spin, forces necessary to reverse the rudder would probably be higher and might possibly be more than the pilot could exert. Model force tests could not be made of the model in the steeper spin because the model could not be held in the tunnel. Calculations were therefore made, based on reference 4, for an unbalanced rudder and on reference 5 for a rudder with 27.9-percent overhang balance, assuming an angle of attack of 25° at the plane of symmetry, and an angle of outward sideslip at the tail of 15°. The calculations showed that the forces to fully reverse the rudders for deflections of ±25° or ±15° would be more than the pilot could exert. Inasmuch as the model test data indicated that recoveries from the steeper spin would be satisfactory by neutralization of the rudders, calculations were made to determine the forces required to neutralize the rudders. The results showed that 1350 pounds would be required to neutralize unbalanced rudders from 25° with the spin and 800 pounds from 15° with the spin, and that 200 pounds would be required to neutralize rudders with 27.9-percent overhang balance from 25° with the spin. These calculations were based on the original-span rudders. For the reduced-span rudders, the magnitude of the forces should be approximately 10 percent less. Rudder balance appears to be the critical element from the above calculation. The XF7U-1 airplane has some overhang balance and a horn balance. The exact amount of balance of the airplane rudders and the scale effects are unknown, but from the limited information available, it appears that the forces calculated for the balanced rudder should give an approximation of the forces expected on the airplane. It therefore appears that the forces required for satisfactory recovery of the airplane may be high but should be within the capabilities of the pilot, as determined in reference 6. With forces of these magnitudes, however, rapid movement of the rudders may be difficult, and, because rapid movement of the rudders is desirable, it may be advisable to install some type of booster in the control system to insure easy and rapid movement of the rudders.

CONCLUSIONS

Based on results of spin tests of a 0.057-scale model of the Chance Vought XF7U-1 airplane, the following conclusions regarding the spin and recovery characteristics of the airplane spinning at an altitude of 15,000 feet are made:

1. The spin and recovery characteristics of the airplane will be satisfactory with the original rudders and reduced deflections or with the reduced-span rudders and original or reduced deflections. Linking the original rudders so that the inboard rudder moves from full with the spin to neutral while the outboard rudder moves from neutral to against the spin will also result in satisfactory spin and recovery characteristics.

2. The pedal forces to move the rudders for recovery should be within the pilot's capabilities; it is believed advisable to have some type of

booster installed in the control system in order to insure easy and rapid movement of the rudders.

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Approved: Charles H. Zimmerman
for Thomas A. Harris
Chief of Stability Research Division

jjm

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3. Neihouse, A. I.: A Mass-Distribution Criterion for Predicting the Effect of Control Manipulation on the Recovery from a Spin. NACA ARR, Aug. 1942.

4. Stone, Ralph W., Jr., and Burk, Sanger M., Jr.: Effect of Horizontal-Tail Position on the Hinge Moments of an Unbalanced Rudder in Attitudes Simulating Spin Conditions. NACA TN 1337, 1947.

5. Stone, Ralph W., Jr., and Burk, Sanger M., Jr.: Hinge-Moment Characteristics of Balanced Elevator and Rudder for a Specific Tail Configuration on a Fuselage in Spinning Attitudes. NACA TN 1400, 1947.

6. Gough, M. N., and Beard, A. P.: Limitations of the Pilot in Applying Forces to Airplane Controls. NACA TN 550, 1936.

TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE CHANCE VOUGHT

XF7U-1 AIRPLANE

Over-all length, ft	36.1
Wing:	
Span, ft	38.6
Area, sq ft	496
Aspect ratio	3.01
Root chord, in.	194.0
Tip chord, in.	116.0
Mean aerodynamic chord, in.	157.0
L.E. $\bar{c}$ rearward L.E. root chord, in.	83.5
Taper ratio	0.60
Incidence (constant), deg	0
Dihedral, deg	0
Sweepback of quarter-chord line, deg	35
Airfoil section	CVA 4-(00)-(12)(40)-(1.1)(1.0)
Ailavator:	
Span, percent b/2	47.2
Total area, sq ft	54
Area rearward of hinge line, sq ft	53
Chord, percent c:	
Inboard station	22.4
Outboard station	29.2
Vertical tail:	
Height, ft	9.1
Total area, sq ft	122
Original rudder area, sq ft	32
Original rudder span, ft	7.1
Reduced rudder span, ft	6.3
Aspect ratio	1.31
Sweepback quarter-chord line, deg	45
Airfoil section	Modified NACA 64-series

[redacted]

TABLE II. - MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE REVISED NORMAL LOADING OF THE CHANCE VOUGHT XF7U-1 AIRPLANE AND FOR THE LOADING TESTED ON THE 0.057-SCALE MODEL

[Model values have been converted to corresponding full-scale values, moments of inertia are given about the center of gravity.]

Weight (lb)	μ		Center-of-gravity location		Moments of inertia (slug-feet^2)			Mass parameters		
	Sea level	15,000 feet	$x/\bar{c}$	$z/\bar{c}$	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										
17,629	12.00	19.08	0.17	0	17,420	27,398	43,845	-122×10^{-4}	-201×10^{-4}	323×10^{-4}
Model										
17,537	11.95	19.00	0.18	0.01	17,622	26,231	43,165	-106×10^{-4}	-208×10^{-4}	314×10^{-4}

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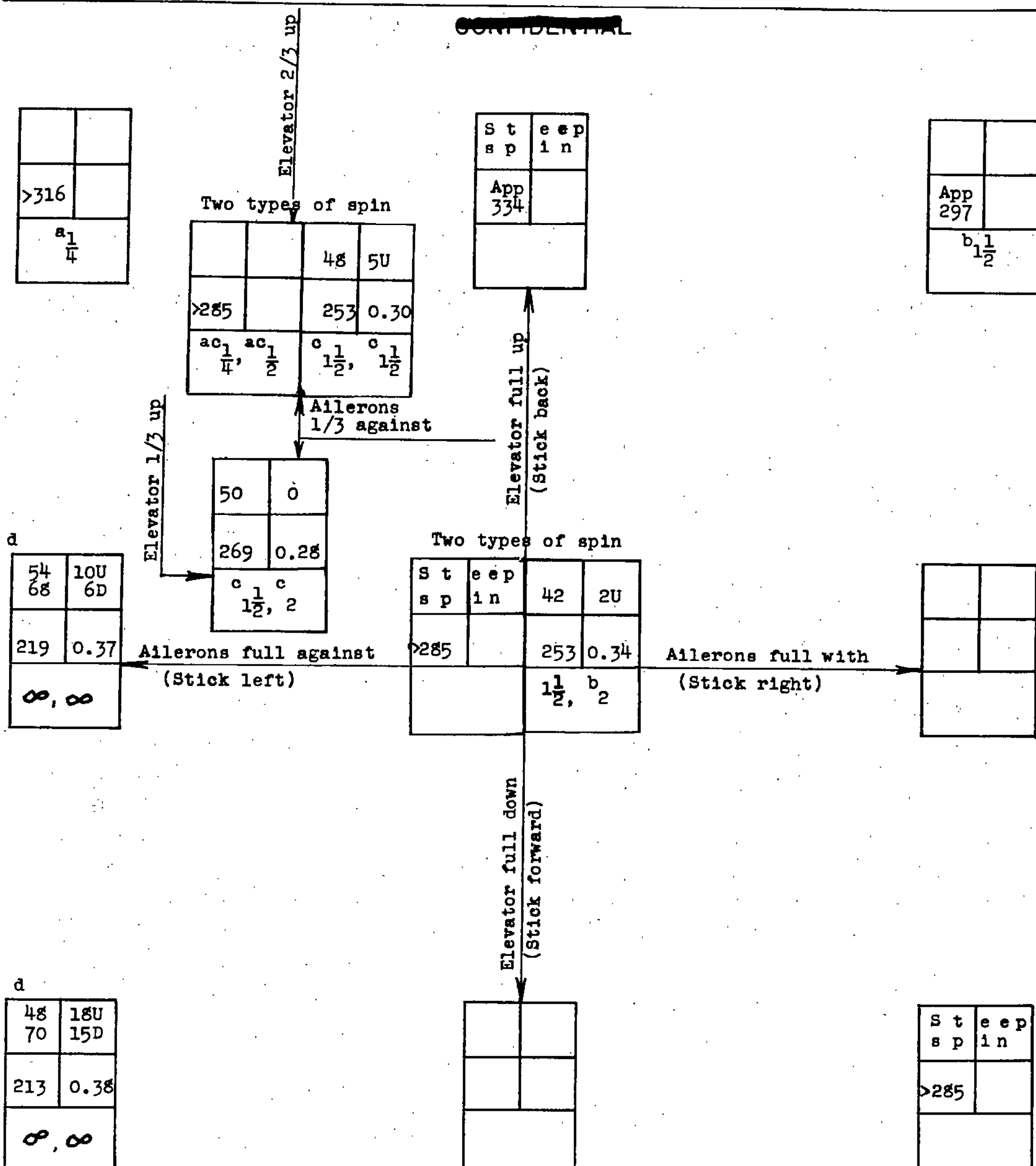
[redacted]

CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE WITH THE ORIGINAL RUDDERS AND ORIGINAL RUDDER DEFLECTIONS (±25°)

[Revised normal loading; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and developed-spin data presented for, rudder-with spins); right erect spins]

[redacted]



[a]Recovery attempted before model in final steeper attitude.
[b]Visual observation.
[c]Recovery attempted by moving rudders from full with the spin to 2/3 against.
[d]Oscillatory spin. Range of values or average value given.

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

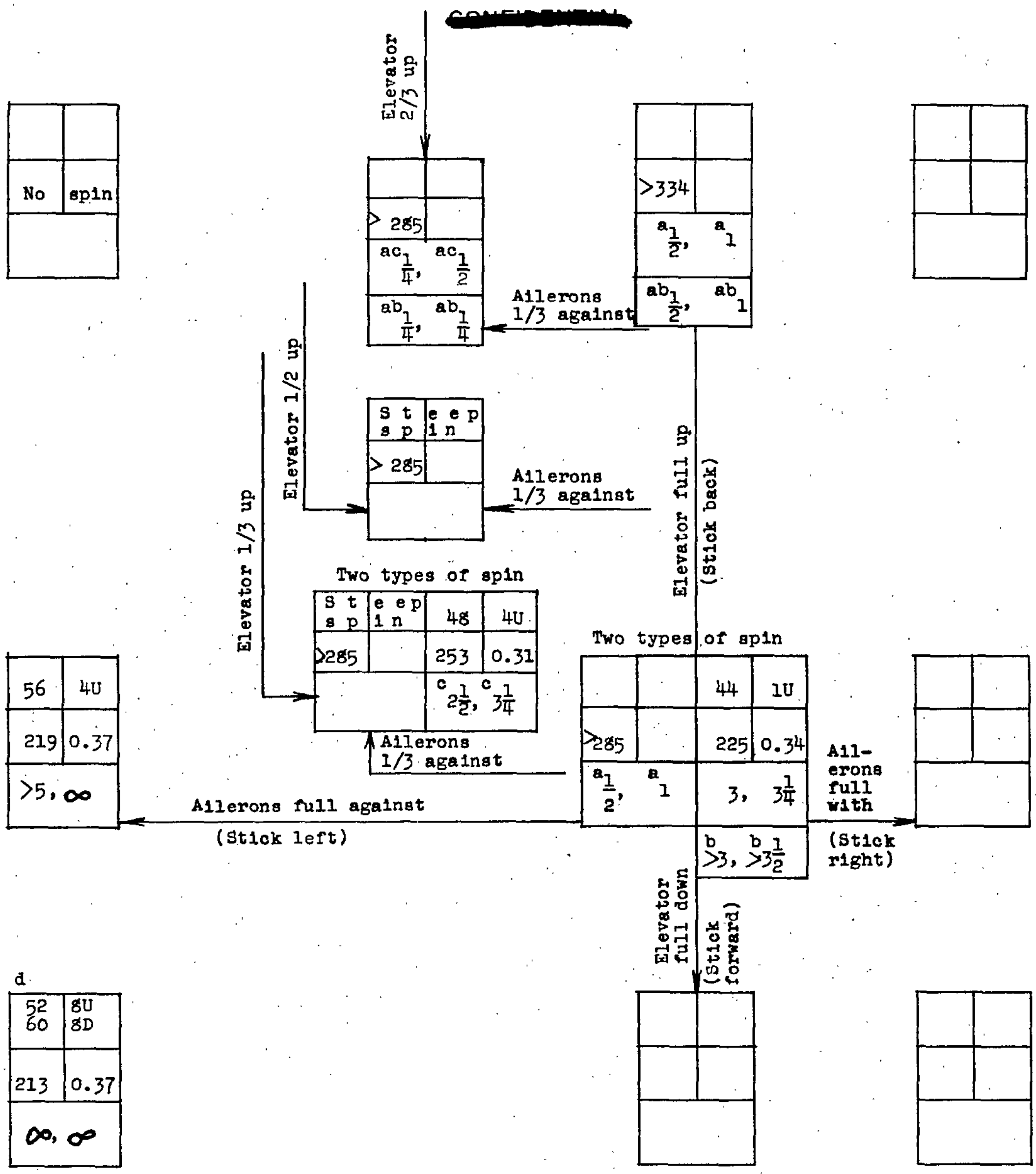
α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

[redacted]

CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE WITH THE ORIGINAL RUDDERS AND REDUCED RUDDER DEFLECTIONS (±15°)

[Revised normal loading; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and developed-spin data presented for, rudder-with spins); right erect spins]

[redacted]



[a]Recovery attempted before model in final steeper attitude.
[b]Recoveries attempted by neutralization of rudders.
[c]Recoveries attempted by reversing rudders from full with to 2/3 against.
[d]Oscillatory spin. Range of values or average value given.

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

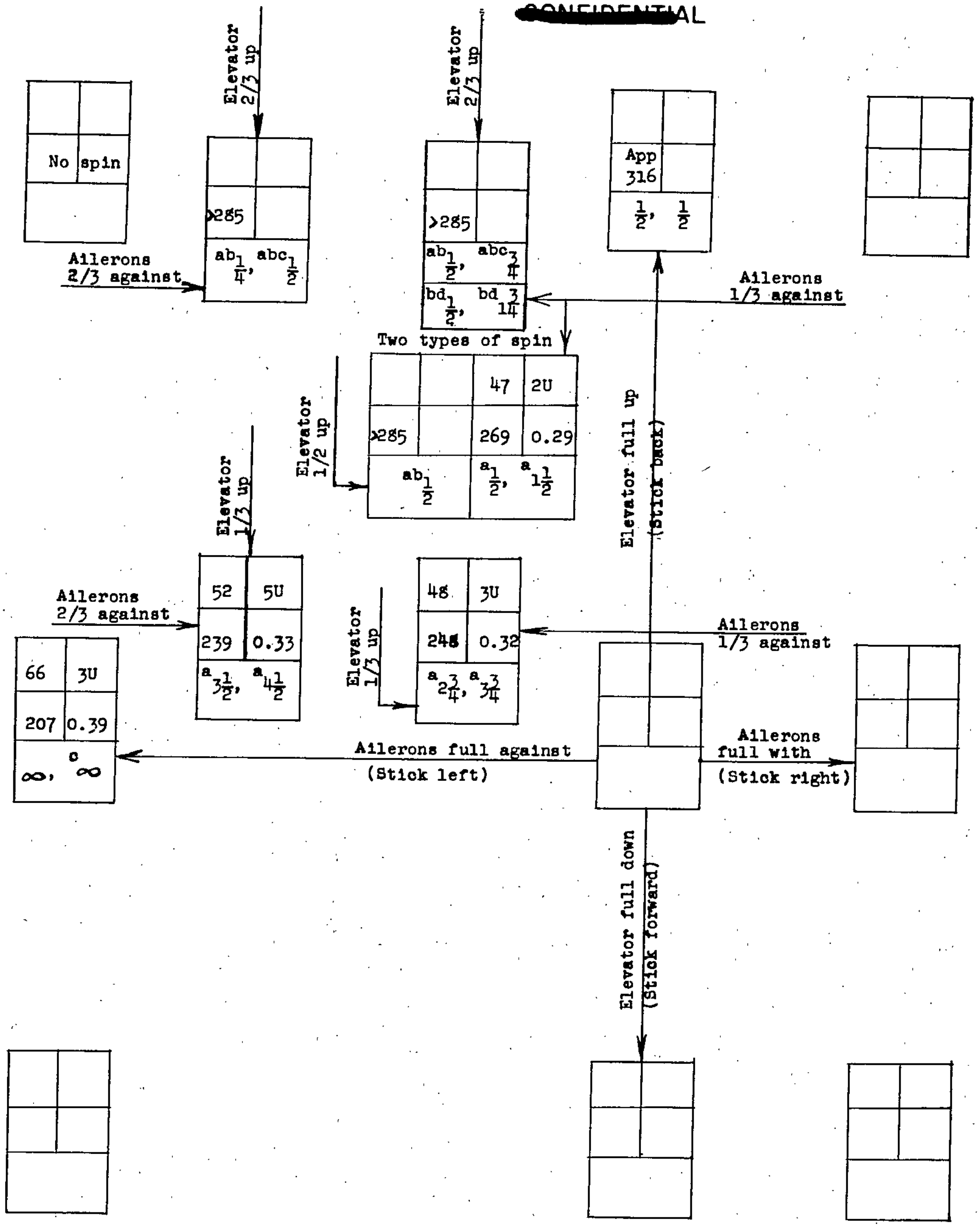
α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

[redacted]

CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE WITH THE REDUCED-SPAN RUDDERS AND ORIGINAL RUDDER DEFLECTIONS (±25°)

[Revised normal loading; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and developed-spin data presented for, rudder-with spins); right erect spins]

[redacted]



[a]Recovery attempted by reversing rudders from full with to 2/3 against.

[b]Recovery attempted before model in final steeper attitude.

[c]Visual observation.

[d]Recovery attempted by neutralization of rudders.

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

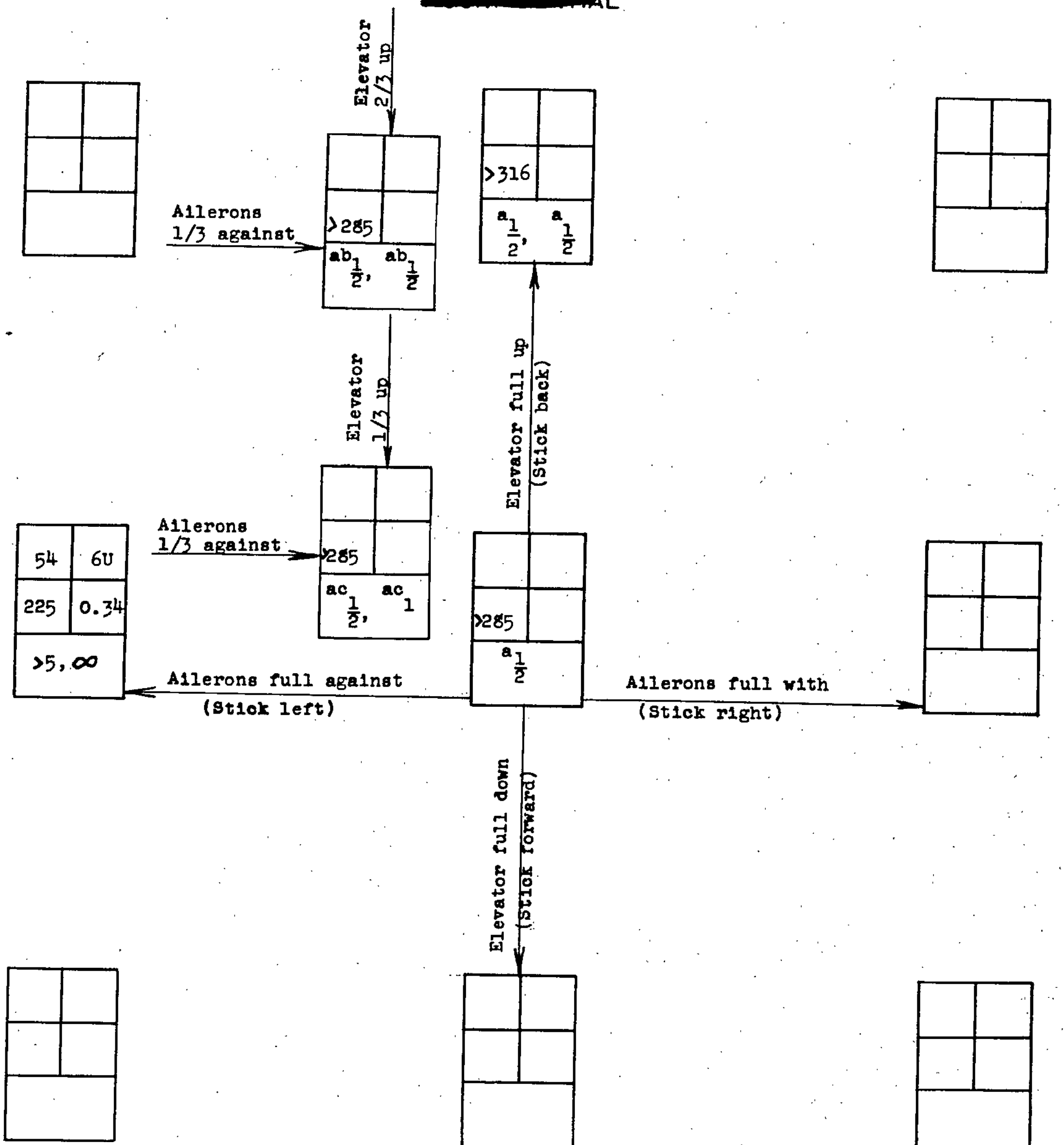
α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

[redacted]

CHART 4.- SPIN AND RECOVERY CHARACTERISTICS OF THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE WITH THE REDUCED-SPAN RUDDERS AND REDUCED RUDDER DEFLECTIONS (±15°)

[Revised normal loading; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from and developed-spin data presented for, rudder-with spins); right erect spins]

[redacted]



[a]Recoveries attempted before model in final steeper attitude.
[b]Recoveries attempted by neutralization of rudders.
[c]Recoveries attempted by moving rudders from full with the spin to 2/3 against.

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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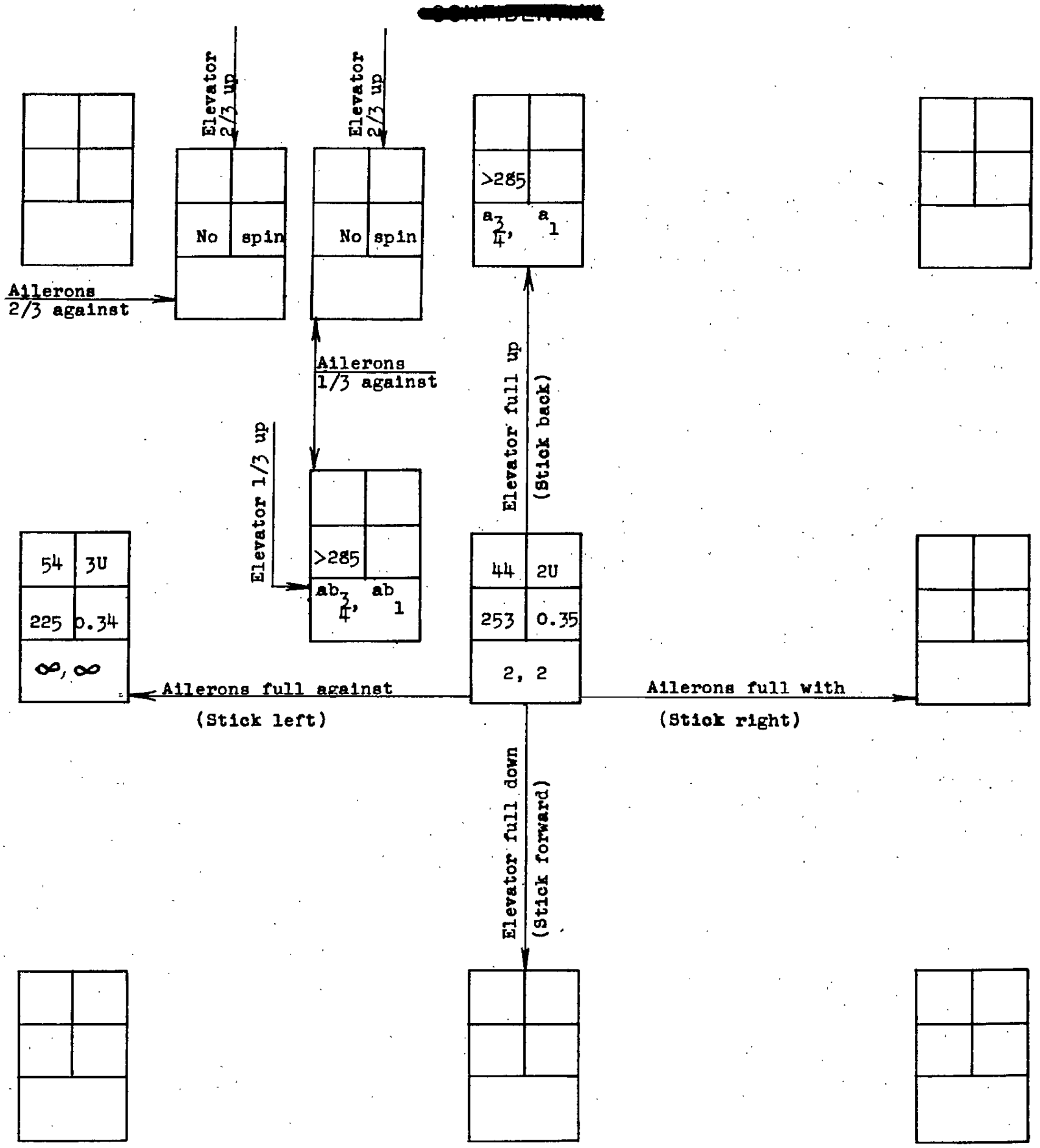
[redacted]

CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE WITH THE ORIGINAL RUDDERS LINKED TO MOVE DIFFERENTIALLY WITH THE ORIGINAL MAXIMUM DEFLECTIONS (±25°)

[Revised normal loading; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and developed-spin data presented for, rudder-with spins); right erect spins]

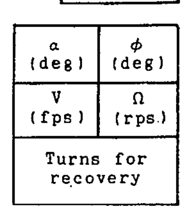
[redacted]



[a]Recovery attempted before model in final steeper attitude.

[b]Recoveries attempted by moving inboard rudder from full with the spin to neutral while moving the outboard rudder from neutral to 2/3 against.

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

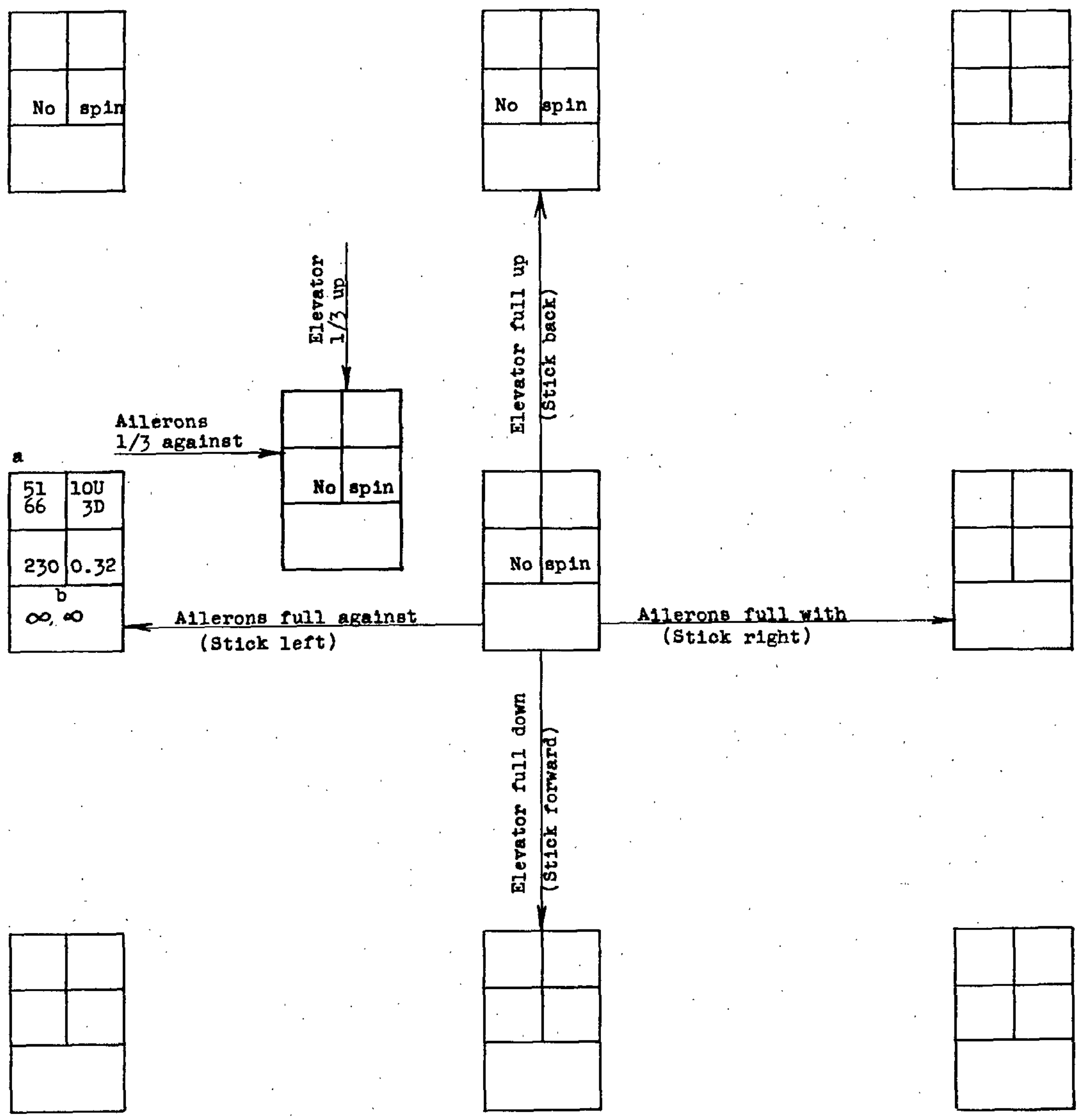


[redacted]

CHART 6.- SPIN AND RECOVERY CHARACTERISTICS OF THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE WITH THE ORIGINAL RUDDERS LINKED TO MOVE DIFFERENTIALLY WITH THE REDUCED MAXIMUM DEFLECTIONS (±15°)

[Revised normal loading; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and developed-spin data presented for, rudder-with spins); right erect spins]

[redacted]



[a]Oscillatory spin. Range of values or average value given.
[b]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	

347

[redacted]

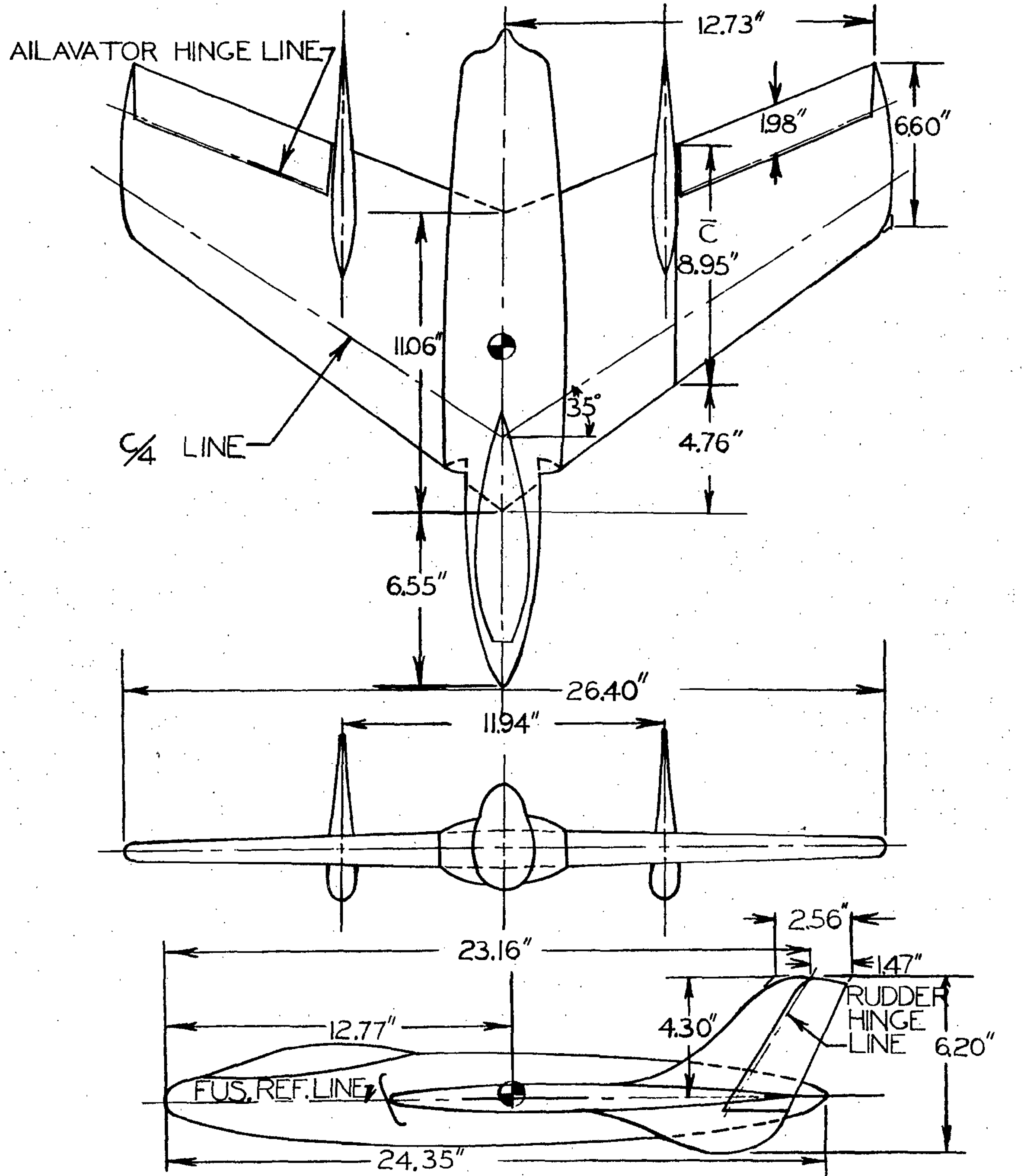


FIGURE 1.- THREE-VIEW DRAWING OF THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE AS TESTED.

[redacted]

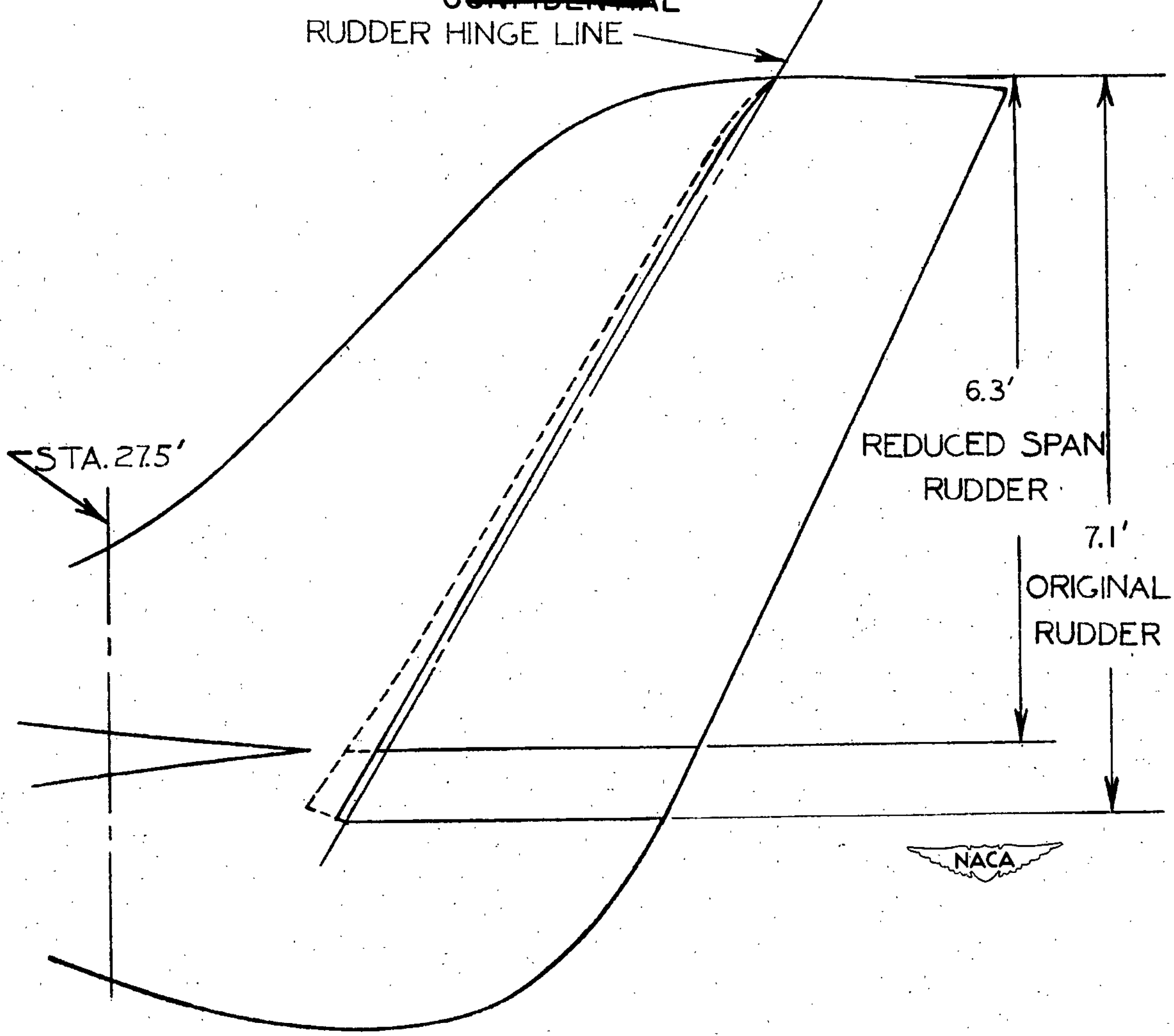


FIGURE 2.- SKETCH OF RUDDERS TESTED ON THE 0.057-SCALE MODEL OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE. DIMENSIONS ARE FULL-SCALE.

[redacted]

[redacted]

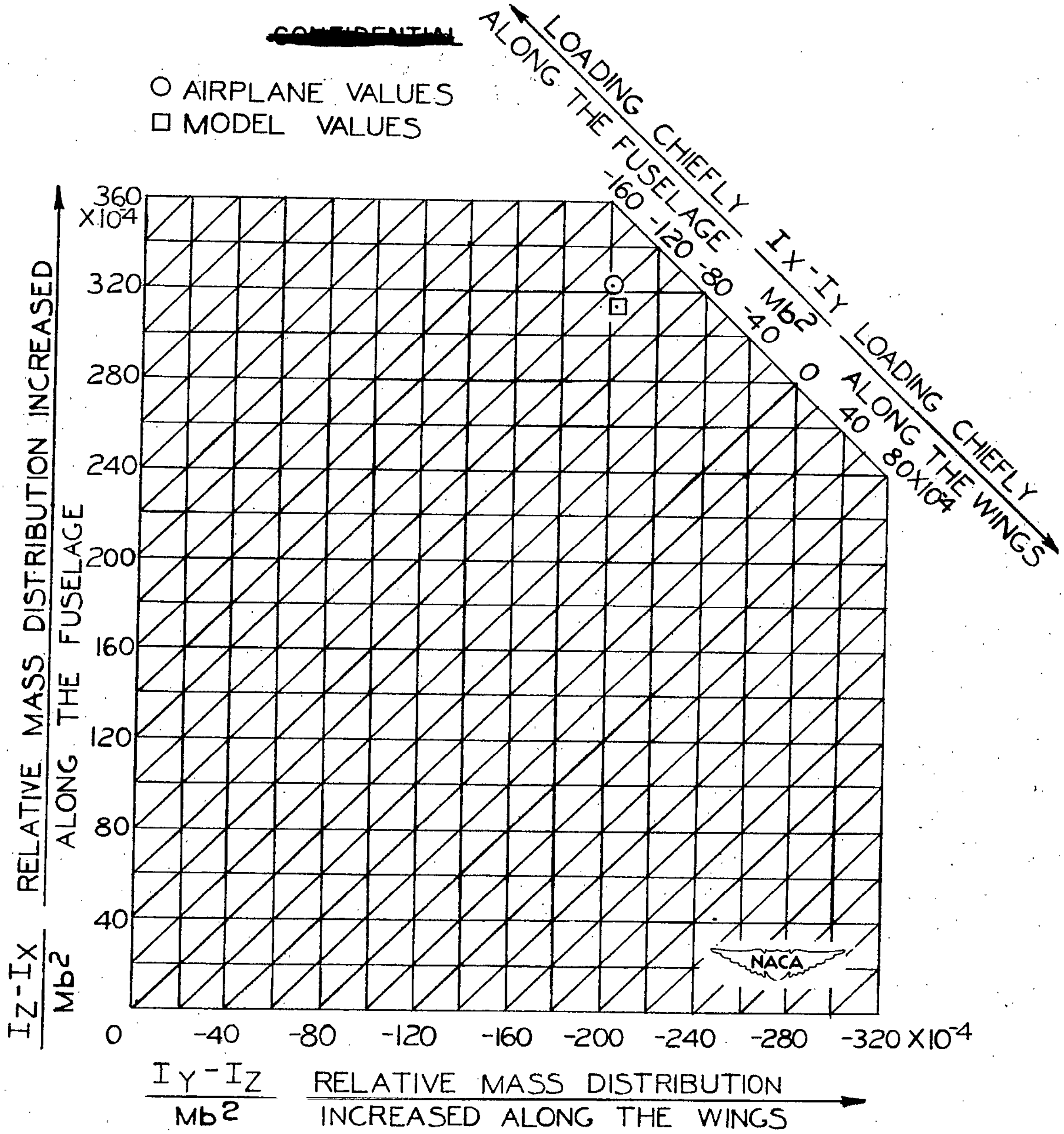


FIGURE 3.-MASS PARAMETERS FOR THE REVISED NORMAL LOADING OF THE CHANCE-VOUGHT XF7U-1 AIRPLANE AND FOR THE LOADING TESTED ON THE 0.057-SCALE MODEL. [redacted]