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RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

FREE-SPINNING, LONGITUDINAL-TRIM, AND TUMBLING CHARACTERISTICS OF A $\frac{1}{20}$-SCALE MODEL OF THE CONSOLIDATED VULTEE MX-813 (PROTOTYPE OF XP-92) AIRPLANE AS DETERMINED IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL

By

Ralph W. Stone, Jr., and Richard P. White

Langley Aeronautical Laboratory
Langley Field, Va.

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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 evaluate the spin, longitudinal-trim, and tumbling characteristics of a $\frac{1}{20}$-scale model of the Consolidated Vultee MX-813 airplane. The effects of control position were determined for the model ballasted to represent the airplane in its design gross weight loading.

The model, in general, would not spin but demonstrated a tendency to trim at very high stalled angles of attack. Static tests substantiated the dynamic tests as regards the trim characteristics. Movement of the elevator, however, from up to slightly down was effective in pitching the model from stalled to normal trim attitudes. The model would not tumble.

INTRODUCTION

At the request of the Air Materiel Command, U. S. Air Force, tests have been performed in the Langley 20-foot free-spinning tunnel to evaluate the free-spinning characteristics of a $\frac{1}{20}$-scale model of the Consolidated Vultee MX-813 airplane. Force tests and tests with the model free to pitch were also performed to determine the longitudinal-trim characteristics of the model at attitudes above the stall. Tumbling tests were also made.

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The MX-813, which is the prototype of the XP-92 airplane, is a flying-wing jet-propelled airplane having a delta plan form the leading apex of which is 60°. Longitudinal and lateral control are combined in one pair of control surfaces called elevons. Two alternate vertical-tail arrangements, which were being considered for the airplane, were tested. One configuration consisted of a single vertical tail in the plane of symmetry, the other consisted of dual vertical tails located at the wing tips. As originally designed, wing fillets termed by Consolidated Vultee "wing plan form dorsal fins" faired the leading edge of the basic wing plan form into the contour of the fuselage. Because of stability considerations, however, the wing fillets have not been incorporated into the prototype airplane and were eliminated from the spin-tunnel model after a few preliminary tests.

With the model in its design gross weight loading, the current investigation included erect and inverted spin tests for the single-vertical-tail configuration, erect spin tests only for the dual-vertical-tail configuration, and tumbling tests for both tail configurations. The investigation also included force tests made for angles of attack ranging from 90° to -90°. Longitudinal-trim tests for which the model was mounted in the tunnel and allowed to rotate freely in pitch about a lateral axis were also performed for the normal center-of-gravity location.

SYMBOLS AND COEFFICIENTS

b	wing span, feet
S	wing area, square feet
$\bar{c}$	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 fuselage reference line to mean aerodynamic chord, positive when center of gravity is below fuselage reference 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 $\left(\frac{m}{\rho Sb}\right)$
α	angle between fuselage reference line and vertical, approximately equal to absolute value of angle of attack at plane of symmetry, degrees
V	full-scale true rate of descent, feet per second
ϕ	angle between span axis and horizontal, degrees
Ω	full-scale angular velocity about spin axis, revolutions per second
q	dynamic pressure, pounds per square foot
C_L	lift coefficient (Lift/qS)
C_D	drag coefficient (Drag/qS)
$C_{M_{\bar{c}/4}}$	pitching-moment coefficient $(M_{\bar{c}/4}/qS\bar{c})$, where $M_{\bar{c}/4}$ is the pitching moment about the 25-percent point of the mean aerodynamic chord
$C_{M_{c.g.}}$	pitching-moment coefficient $(M_{c.g.}/qS\bar{c})$, where $M_{c.g.}$ is the pitching moment about the center of gravity of the airplane
ψ	angle of yaw about the Z-body axis, degrees
δ_e	elevator deflection, positive when trailing edge is down, degrees
δ_a	aileron deflection, degrees
δ_r	rudder deflection, positive when trailing edge is to the left, degrees

APPARATUS AND METHODS

Model

The $\frac{1}{20}$ scale model of the Consolidated Vultee MX-813 airplane was built by the manufacturer. It was checked for dimensional accuracy and prepared for testing at the Langley Laboratory. At the inception of the current tests, two different vertical-tail configurations were under consideration. Also, the inclusion of the wing fillets was on a tentative basis. The three-view drawing of figure 1 shows the airplane with its basic wing plan form and single vertical tail. The dashed lines show the shapes and dimensions of the dual vertical tails and the wing fillets. The dimensional characteristics of the airplane as represented by the model are given in table I.

The model with the single vertical tail and with the dual vertical tails is shown in the photographs of figure 2. The wing fillets which were included on the model when it was constructed are shown in both photographs. The wing fillets, as previously indicated, were removed from the model after a few preliminary tests. The full-scale wing area with the single vertical tail represented by the model as received from the manufacturer and used for the current tests was 375 square feet. Although the prototype airplane, as subsequently designed, had 425 square feet of wing area, it was felt that the differences in wing area would not appreciably affect the results and therefore no change was made on the model.

As previously indicated, lateral and longitudinal control are combined in one pair of surfaces called elevons. Longitudinal control is obtained by deflection of the elevons together, and lateral control is obtained by differential deflections of the elevons. Hereafter, in this report, elevon deflections for longitudinal and lateral control will be referred to, for simplicity, as elevator and aileron deflections, respectively.

The model was ballasted with lead weights to obtain dynamic similarity to the prototype airplane at an altitude of 15,000 feet (ρ = 0.001496 slug per cubic foot). The weight, moments of inertia, and center-of-gravity location used in ballasting the model were obtained from information furnished by Consolidated Vultee.

A remote-control mechanism was installed in the model to actuate the controls for recovery. Sufficient moments were exerted on the control surfaces to move them quickly and completely from the present position to the position desired.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that described in reference 1 for the Langley 15-foot free-spinning tunnel.

Spin tests.- The launching technique for the model has been changed from that described in reference 1 to that in which the model is launched by hand with rotation into the vertically rising air stream which is adjusted until the force of the rising air stream balances the weight of the model. Recovery from this motion is attempted by moving one or more controls by means of a remote-control mechanism. If recovery is effected, the model glides or dives into a safety net. Visual observations and motion-picture records are made of the motion exhibited by the model.

In accordance with standard spin-tunnel procedure, tests are performed to determine the spinning characteristics of the model for the normal control configuration for spinning (elevator full up, ailerons neutral, and rudder full with the spin) and for various other elevator-aileron control combinations involving maximum, intermediate, and neutral displacements of one or both of these control surfaces. Normally, recovery from the spin is attempted by rapid rudder reversal or by reversal of rudder and elevator. To evaluate the possible adverse effects on spin and recovery of small deviations from the normal control configuration for spinning, the elevator is set at two-thirds of its full-up deflection (stick two-thirds back) while the ailerons are set either one-third against the spin (stick left in a right spin) or one-third with the spin (stick right in a right spin), depending upon which aileron setting will lead to the most critical condition. For some models, aileron settings in both directions are tested if it is not obvious which direction will be adverse. Recovery from the spin is normally attempted by reversing the rudder from full with the spin to only two-thirds against the spin. This particular control configuration and manipulation is referred to as the "criterion spin."

Cessation of the initial spinning motion imparted to the model at launching without movement of controls is designated as "no spin."

Force tests.- The lift, drag, and pitching-moment data were obtained by mounting the model on a six-component strain-gage balance in the Langley 20-foot tunnel.

Longitudinal-trim tests.- For the investigation of the longitudinal-trim characteristics, the model was mounted at its center of gravity in such a manner that the stability Y-axis was the only axis of freedom (freedom in pitch). At the test airspeed the model was forcibly displaced from its normal trimmed position by means of a long pole so that the angle of attack ranged through approximately $\pm 90^{\circ}$. It was then left free to assume its original trim attitude or to seek another. Figure 3 is a photograph showing the model as it was mounted for testing in the Langley 20-foot spin tunnel.

Tumbling tests.- Two methods of launching were employed in determining the susceptibility of the model to tumbling. For one method, the model was held at an attitude approximately 180° to the vertical air stream and was then dropped, thus simulating a whip-stalled condition. For the second method of launching, the model was again held at approximately 180° to the air stream and then, however, it was given an initial pitching rotation by hand. The resulting motions were observed and photographed.

If a model tumbles with either method of launching, it is taken as an indication that the corresponding airplane can tumble although the airplane probably would be more likely to tumble if the model started tumbling when launched with no pitching rotation. If the model stops tumbling after being launched with initial pitching rotation, the results are interpreted to mean that the corresponding airplane definitely will not tumble.

PRECISION

The model spin test results are believed to be 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:	Obtained from motion-picture records	$\pm\frac{1}{4}$
	Obtained visually	$\pm\frac{1}{2}$

The preceding limits may have been exceeded for a portion of the spins in which it was difficult to control the model in the tunnel because of the wandering or oscillatory nature of the spin.

Comparison between model and full-scale spin results (references 1 and 2) indicates that spin-tunnel results are not always in complete agreement with airplane spin results. In general, the models spin at somewhat smaller angles of attack, at somewhat higher rates of descent, and with 5° to 10° more outward sideslip. This comparison was made, however, for conventional airplane designs and may not be applicable to the MX-813 airplane.

Because of the impracticability of ballasting the model exactly and because of inadvertent damage suffered by the model during the tests, the measured weight and mass distribution of the model varied from the true scaled-down values by amounts within the following limits:

Weight, percent		0 to 2 high
Center-of-gravity location, percent $\bar{c}$		0
Moments of inertia:	I_X	0 to 8 high
	I_Y	1 low to 2 high
	I_Z	0 to 1 high

The accuracy of measuring the weight and mass distribution is believed to be within the following limits:

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

The controls were set with an accuracy of $\pm 1^{\circ}$.

TEST CONDITIONS

Tests were performed for the model conditions listed on table II. The mass conditions and inertia parameters for the loadings tested on the model (converted to full-scale values) and for the loadings possible on the airplane are listed on table III and plotted on figure 4.

The maximum control deflections used in the tests were:

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

Intermediate control deflections tested were:

Elevons, degrees:
Deflected as elevators:
One–quarter . . . . 5 up
Two–thirds . . . . $13\frac{1}{3}$ up, $13\frac{1}{3}$ down
Deflected as ailerons:
One–quarter . . . . $3\frac{3}{4}$ up, $3\frac{3}{4}$ down
One–third . . . . 5 up, 5 down
One–half . . . . $7\frac{1}{2}$ up, $7\frac{1}{2}$ down
Two–thirds . . . . 10 up, 10 down

The same maximum control deflections were used for both vertical-tail configurations. Figure 5 shows the angular deflections of the elevons plotted against stick position.

For all tests, the landing gear was retracted and the cockpit canopy was closed.

The force tests were made at a q of 4 pounds per square foot and a corresponding Reynolds number of approximately 0.3×10^6. The tunnel turbulence factor is 1.8. The Reynolds number was calculated on the basis of the model mean aerodynamic chord of 0.85 foot. No tunnel–wall or blocking corrections have been applied to the force data because of the small size of the model relative to the diameter of the tunnel. As previously indicated, the angle–of–attack range for which the force tests were performed was 90° to –90°.

The tests with the model free to pitch were performed for the normal center–of–gravity location of 24 percent of the mean aerodynamic chord.

RESULTS

The results of the model spin tests are presented in charts 1 to 4, having been converted to full–scale values for the airplane at an altitude of 15,000 feet by methods described in reference 1. The model gave similar results when launched with spinning rotation either to pilot's right or left and therefore all spinning results are arbitrarily presented for rotation to pilot's right, only. The results of tests to determine the effects of elevator movement on the model motion following launching for spin tests are presented on table IV. The lift, drag, and pitching–moment data for the model from –90 to 90° angle of attack are plotted on figure 6. The results of the tumble tests for both the single- and dual-vertical-tail configurations are presented on table V.

DISCUSSION

Spin Tests

<u>Single-vertical-tail configuration</u>.- The results of spin tests for the model with the single-vertical-tail configuration loaded to represent the prototype airplane in its design gross weight loading (model loading 1 on table III and figure 4) are given in chart 1. The model would not spin for any control configuration. For the normal control configuration for spinning (elevator up, ailerons neutral, and rudder full with the spin), the launching rotation was expended rapidly and the model trimmed at an angle of attack of 56°. When the elevator was neutral, ailerons neutral, the model trimmed in a steep unstalled dive, and when the elevator was full down, the model trimmed inverted at a stalled negative attitude ($\alpha = -85^\circ$).

With the ailerons set full against the spin for all elevator settings, the launched spinning rotation was damped very rapidly and a rolling oscillation started which increased in magnitude until the model rolled continually about the longitudinal body axis. The angle between the longitudinal body axis and the air stream was well above the stall for all elevator positions.

For the criterion spin with the ailerons set at one-third of their full deflection against the spin, the rolling motion was again evident, commencing simultaneously with the cessation of the enforced spin rotation. The angle between the longitudinal body axis and the direction of the air stream was 75°. Strip film from motion-picture records showing the cessation of the hand-forced spin rotation and the ensuing rolling motion is shown in figure 7.

An investigation of various other intermediate settings of ailerons against the spin and elevator up was made to determine the limits of control positions (elevator and ailerons) for which steep conditions would exist. With the elevator neutral, steep conditions were obtained unless the aileron deflection against the spin was one-half the full deflection or greater. With the elevator as little as one-fifth up, however, for any aileron-against settings, flat conditions appeared possible. It appears, therefore, that aileron-against settings should be avoided on the airplane and that up-elevator deflections will be conducive to flat trim attitudes on the airplane.

When the ailerons were set with the spin, results similar to those for ailerons neutral were obtained.

The results of tests performed to establish the effect of movement of the elevator down during the stalled attitudes resulting when the imposed spin rotational motion of the model had ceased are presented in table IV. The results indicate that, in order to obtain effective control over the stalled trim, movement of the stick somewhat forward of neutral should be adequate. Moving the elevator to neutral did not appear sufficiently effective while moving the elevator from full up to full down caused the model to pitch inverted and to trim inverted at a stalled attitude.

In order to effect recovery from a stalled attitude which may be encountered, it is recommended that the stick be pushed forward of neutral longitudinally and neutralized laterally. Care should be exercised to keep the stick from reaching its maximum longitudinally forward position to prevent the possibility of the airplane trimming on its back. Care should also be exercised to avoid aileron-against control settings.

The results of preliminary tests made with the single-vertical-tail configuration with wing fillets installed on the model are presented in chart 2. Comparison of these results with those of chart 1 shows a definite adverse effect of the wing fillets in that flat spins were obtained for some control configurations and flat stalled attitudes persisted even for conditions in which the elevators were neutral.

Dual-vertical-tail configuration.- The results for the model with the dual-vertical-tail configuration (loading 6 on table III and figure 4) are given in chart 3 and table IV. The characteristics of the model with the dual vertical tails are similar to those for the single-vertical-tail configuration. The rolling motion obtained, when the ailerons were deflected against the spin, with the single vertical tail did not exist with the dual vertical tails, but an oscillatory wallowing motion existed in its place. It is recommended that the same techniques for recovery from stalled trimmed conditions recommended for the single-vertical-tail configuration be used for the dual-vertical-tail configuration.

Inverted spins.- The results of the inverted spin tests performed on the model for the single-vertical-tail configuration are given on chart 4 for launching rotations to the pilot's right. The order used in presenting data for inverted spins is different from that used for erect spins. For inverted spins, "controls crossed" for the established spin (right rudder pedal forward and stick to pilot's left for a spin to pilot's right) is presented to the right of the chart and "stick back" at the bottom of the chart. When the controls are "crossed" in the established inverted spin, the ailerons aid the rolling motion; when the controls are "together," the ailerons oppose the rolling motion. The angle of wing tilt ϕ on the chart is given as up or down relative to the ground.

For all control configurations, except those for which the controls were together and the stick was neutral, two-thirds or full forward longitudinally, the model would not spin but was violently oscillatory in roll, generally rolling continually about the longitudinal body axis or rolling to an erect attitude. The ensuing motions were, in general, similar to those described for erect spin tests with similar control configurations. The inverted spins obtained were smooth and steady and at high angles of attack ($\alpha = 76^\circ$ to 82°). Recovery from the spin in which the stick was longitudinally full forward was effected in one turn by rapid full rudder movement against the spin. Following recovery from this spin, the model dived steeply with some oscillation in roll. Recovery was not attempted from the other spins but the results of tests for all three spins when launched with the rudder preset full against the spin (left rudder pedal forward, when launched with rotation to the pilot's right) were similar, indicating rapid recovery characteristics for all spins. The results indicate that recovery from any inverted spin obtained should be possible by reversing the rudder and neutralizing the stick laterally and longitudinally.

Loading variations.- Inasmuch as the spin and recovery characteristics of the model with the single and dual vertical tails installed were very similar, it appears that the difference in loading between the two conditions (loadings 1 and 6 on table III and figure 4) had little or no influence on the spin and recovery characteristics and it was therefore felt that the spin and recovery characteristics of the model for the other possible loadings for the prototype airplane (table III and figure 4), would be similar to the results presented in charts 1 and 3.

Static Force Tests

The results of the static force tests are presented in figure 6. The three elevator positions of full up, neutral, and full down were used in obtaining the force and moment data.

With the elevator full up, the pitching-moment curve (C_M against C_L) indicates a trim condition for the model at $\alpha = 60^\circ$ in figure 6(a) which is in good agreement with the spin results where it was shown that the model trimmed at $\alpha = 56^\circ$ following cessation of the spinning rotation.

In figure 6(b) for $\delta_e = 0^\circ$, two trim conditions are shown for the model, one in the normal angle-of-attack range and the other above the stall (α approximately 54°). Force and moment results for a delta wing plan form, with no fuselage, obtained at approximately the same Reynolds number have been compared to the results for the model at $\delta_e = 0^\circ$ and are shown in the same figure. It may be inferred from the comparison that the highly stalled trim attitude, shown possible for the model, is due to fuselage interference. Dynamic test results for the same control configuration (chart 1) show only a steep trim condition following cessation of launching rotation. Tests of elevator movement (table IV), however, show that when the elevator is moved from up to neutral, recovery from stalled attitudes (existing when the elevator was up) was not sufficiently reliable to be considered satisfactory, indicating some influence of the apparent second trim condition with elevators neutral as shown in figure 6(b).

Reference to the results obtained for the elevator-full-down setting given in figure 6(c) shows a neutrally stable condition (dC_M/dC_L approximately 0) in the positive angle-of-attack quadrant (0° to 90°) and a trim condition at a high negative angle of attack ($\alpha = -60^\circ$). For the spin tests, the model trimmed at a similarly high negative angle of attack.

Figure 6(d) presents a comparison between pitching-moment data obtained for the subject model and that obtained for a $\frac{1}{12.78}$-scale model of the MX-813 airplane in the GALCIT 10-foot wind tunnel at $\delta_e = 0^\circ$. The data show good agreement up to $C_L = 1.0$. Above $C_L = 1.0$, however, in the stalled region, there is a discrepancy as the data show the subject model to be unstable and the $\frac{1}{12.78}$-scale GALCIT model to be stable in pitch. This discrepancy in the respective stability characteristics of the two models in the region of the stall may be attributed to the Reynolds number difference at which the two models were tested; the Reynolds number for the GALCIT tests was 2×10^6 while that for the current tests was 0.3×10^6. Insofar as the GALCIT tests, which were performed at the higher Reynolds numbers, more nearly approximate full-scale conditions, the force data obtained for the spin model should be regarded as being conservative as regards longitudinal trim characteristics.

Longitudinal-Trim Tests

The results of the longitudinal-trim tests show that with the model mounted in the tunnel on a lateral axis through the normal center-of-gravity location, trim attitudes were obtained for three elevator settings which qualitatively verified the results of trim attitudes obtained for the spin and static force tests. These results are not published in detail in this report.

Tumbling Tests

The results of tumbling tests with the single-vertical-tail configuration and with the dual-vertical-tail configuration are presented in table V. As explained previously, two methods of launching the model were employed: for one method the model was launched from a nose-up position to simulate a whip stall; for the second method, the model was given an initial tumbling rotation about a lateral axis. The results indicate that for either tail configuration the model exhibited no tendency to tumble. Whether launched from a nose-up position to simulate a whip stall or given an initial pitching rotation about a lateral axis, the pitching rotation was heavily damped.

CONCLUSIONS

The following conclusions have been made based on dynamic and static tests which were performed on a $\frac{1}{20}$-scale model of the Consolidated Vultee MX-813 airplane in its design gross weight loading in the Langley 20-foot free-spinning tunnel:

1. The airplane will not spin erect but may trim at high stalled angles of attack when the stick is back longitudinally. Neutralization of the stick laterally and movement of the stick forward of neutral is recommended to regain unstalled flight. Aileron-against settings should be avoided.

2. The airplane may spin inverted when the controls are together and may trim inverted at high stalled angles of attack when the stick is forward longitudinally. Rapid rudder reversal is recommended to terminate the spin and neutralization of the stick laterally and movement of the stick rearward of neutral is recommended to regain unstalled flight.

3. The airplane will not tumble.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

Ralph W. Stone, Jr.
Aeronautical Research Scientist

Richard P. White
Aeronautical Research Scientist

Approved: Joseph A. Shortal
for Thomas A. Harris
Chief of Stability Research Division

KBC

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2. Hale, M.: Preliminary Mass Distribution and Moments of Inertia. Model 7002, Rep. No. Devf. 2037-A, Oct. 14, 1946 (Revised Jan. 15, 1947)

3. Sumrall, Calhoun: Report on Additional (C) Wind-Tunnel Tests of a $\frac{1}{12.78}$-Scale Model of the Consolidated Vultee (Vultee Field) Model 115 Airplane. GALCIT Report 515-C, June 18, 1947.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE CONSOLIDATED VULTEE MX-813 AIRPLANE AS SIMULATED ON THE $\frac{1}{20}$-SCALE SPIN MODEL

	Single vertical tail	Dual vertical tails
Length, over-all, feet	41.37	41.37
Wing:		
Span, feet	29.42	22.83
Area, square feet	375.0	366.4
Section, parallel to airplane center line	NACA $65_{(006)}$-006.5	NACA $65_{(006)}$-006.5
Mean aerodynamic chord, feet	16.99	16.99
Leading edge $\bar{c}$ behind leading apex angle wing, inches	101.98	101.98
Sweepback of leading edge of wing, degrees	60	60
Tip chord, inches	0	68.6
Root chord, inches	305.8	305.8
Wing dihedral, degrees	0	0
Taper ratio	0	0.224
Aspect ratio	2.32	1.42
Center of gravity to elevon hinge, feet	10.53	10.53
Center of gravity to rudder hinge, feet	11.86	11.86
Elevon:		
Chord behind hinge line (constant), inches	34.4	34.4
Area of each elevon behind hinge line, square feet	33.2	25.73
Vertical tail:		
Total area, square feet	67.0	47.26 each
Rudder area behind hinge line, square feet	13.4	7.3 each
Chord behind hinge line (constant), inches	19.2	21.0
Aspect ratio (b^2/S)	1.15	1.28

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TABLE II.– MODEL CONDITIONS TESTED ON THE $\frac{1}{20}$-SCALE MODEL OF THE MX-813 AIRPLANE

(a) Dynamic Tests

Simulated full-scale loading	Type of launching	Model configuration	Data presented in
Spin tests			
Design gross weight	Erect spin	Single vertical tail	Chart 1
Design gross weight	--------do-------	Single vertical tail and wing fillets	Chart 2
Design gross weight	--------do-------	Dual vertical tail	Chart 3
Design gross weight	Inverted spin	Single vertical tail	Chart 4
Dynamic elevator movement tests			
Design gross weight	Erect spin	Single vertical tail	Table IV
Design gross weight	--------do-------	Dual vertical tail	Table IV
Tumbling tests			
Design gross weight	Tumbling	Single vertical tail	Table V
Design gross weight	--------do-------	Dual vertical tail	Table V

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TABLE II.– MODEL CONDITIONS TESTED ON THE $\frac{1}{20}$-SCALE MODEL OF THE MX-813 AIRPLANE (Concluded)

(b) Static Tests[a]

Model configuration	$x/\bar{c}$	Elevator setting, δ_e (deg)	Aileron setting, δ_a (deg)	Rudder setting, δ_r (deg)	Data presented in
Single vertical tail	0.241	–20	0	0	Figure 6
Single vertical tail	.241	0	0	0	Figure 6
Single vertical tail	.241	20	0	0	Figure 6

[a] q = 4 pounds per square foot; $\psi = 0^{\circ}$; Reynolds number = 0.3×10^6.

[redacted]

[redacted]

TABLE III.– MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR VARIOUS LOADINGS POSSIBLE ON THE CONSOLIDATED VULTEE MX-813 AIRPLANE AND FOR THE LOADINGS TESTED ON THE MODEL

[Model values are given as corresponding full-scale values; moments of inertia are given about the center of gravity]

No.	Loading	Weight (lb)	Center-of-gravity location		Relative airplane density (μ)		Moments of inertia (slug-feet^2)			Mass parameters		
			$x/\bar{c}$	$z/\bar{c}$	Sea level	Altitude 15,000 feet	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, (a) single vertical tail												
1	Design gross weight	11,600	0.241	0.002	13.73	21.82	4,110	27,270	29,629	-742×10^{-4}	-76×10^{-4}	818×10^{-4}
2	Design gross weight less 1/2 fuel	10,337	.241	.002	12.23	19.4	3,920	26,985	29,386	-830	-86	916
3	Design gross weight less all fuel	9,075	.241	.002	10.74	17.07	3,748	26,730	29,149	-942	-99	1041
4	Design gross weight – most forward center of gravity	10,529	.226	.002	12.46	19.81	3,945	27,029	29,423	-815	-85	900
5	Design gross weight – most rearward center of gravity	10,143	.254	.002	12.0	19.08	3,902	26,925	29,309	-844	-87	931
Model values												
1	Design gross weight	11,648	0.240	0.014	13.80	21.93	3,989	27,619	29,557	-754×10^{-4}	-62×10^{-4}	816×10^{-4}
Airplane values, (b) dual vertical tails												
6	Design gross weight	11,600	0.241	0.002	18.11	28.79	4,721	27,061	30,475	-1190×10^{-4}	-182×10^{-4}	1372×10^{-4}
Model values												
6	Design gross weight	11,598	0.241	0.002	18.10	28.78	4,713	27,078	30,560	-1192×10^{-4}	-186×10^{-4}	1378×10^{-4}

[redacted]

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TABLE IV.– THE EFFECT OF ELEVATOR MOVEMENT ON THE LONGITUDINAL TRIMMING CHARACTERISTICS OF THE MODEL

[Elevator moved when launching rotation had damped; design gross weight (loadings 1 and 7 on table III and figure 4); landing gear retracted; cockpit closed; rudder full with direction of rotation]

Aileron position	Elevator movement	Angle of attack of model before elevator movement, α (deg)	Behavior of model following elevator movement
		Single vertical tail	
Neutral	Full up to neutral	56	Model pitches to $\alpha = 37^\circ$ approximately, and after making one spiraling turn glides at a somewhat smaller unstalled angle of attack
Do-----	Full up to 1/4 down	56	Model pitches to very steep angle of attack (α close to 0°) and dives at this attitude or a small negative attitude ($\alpha = -5^\circ$)
Do-----	Full up to 1/2 down	56	Model pitches to very steep angle of attack (α close to 0°) and dives out at small negative attitude ($\alpha = -10^\circ$)
Do-----	Full up to 3/4 down	56	Model pitches inverted and trims in a stalled inverted attitude ($\alpha = -65^\circ$, approximately) glide
Do-----	Full up to full down	56	Model pitches inverted and trims in a stalled inverted attitude ($\alpha = -65^\circ$, approximately) glide
Full with	Full up to neutral	64	Model pitches to $\alpha = 44^\circ$ and trims in this stalled attitude with slight rolling oscillation
Do -----	Neutral to full down	42	Model pitches to $\alpha = 25^\circ$ and after one spiraling turn, rolls inverted and dives at $\alpha = -20^\circ$
Full against	Neutral to full down	71	Model pitches to $\alpha = 65^\circ$; remaining in this stalled attitude commences rolling about the longitudinal body axis (rolling motion is with ailerons)
		Dual vertical tails	
Neutral	Full up to neutral	61	Model pitches to $\alpha = 25^\circ$, approximately, then dives out rolling about longitudinal body axis
Do-----	Full up to 1/4 down	61	Model pitches to $\alpha = 9^\circ$, approximately, then dives out at this attitude
Do-----	Full up to 1/2 down	61	Model pitches to $\alpha = 31^\circ$ and glides out either (a) erect or (b) rolls inverted and glides out inverted
Do-----	Full up to 3/4 down	61	Model pitches to $\alpha = 48^\circ$ then rolls to inverted attitude for which $\alpha = -60^\circ$ and trims in glide at this attitude
Do-----	Full up to full down	61	Model immediately pitchs to an inverted attitude ($\alpha = -60^\circ$) and trims in a glide at this attitude

[redacted]

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TABLE V.– TUMBLING TESTS OF THE $\frac{1}{20}$-SCALE MODEL OF THE MX-813 AIRPLANE

[Design gross weight (loadings 1 and 7 on table III and figure 4); landing gear retracted; cockpit closed; rudder neutral]

Elevator setting	Aileron setting	Tunnel airspeed (ft/sec full scale)	Behavior of model following release
Single vertical tail			
(a) Model launched nose up to simulate a whip stall			
Up	Neutral	147	Tumbling rotation heavily damped – model trims in a steep glide after $\frac{1}{2}$ revolution in pitch
Neutral	Neutral	147	Model made $\frac{3}{4}$ to $1\frac{1}{2}$ turns in tumble then trimmed inverted in (a) a spin or (b) began to roll about the longitudinal body axis
Down	Neutral	147	Tumbling rotation heavily damped model trims in a glide spiraling to the right after 1 to $1\frac{1}{2}$ pitching revolutions
(b) Model given an initial pitching rotation about a lateral axis			
Up	Neutral	147	Model made $1\frac{1}{2}$ turns in tumble then trimmed in a steep glide
Neutral	Neutral	147	Model made $\frac{3}{4}$ turn in tumble then trimmed in a steep glide
Down	Neutral	147	Model made $\frac{3}{4}$ turn in tumble then trimmed in a steep glide
Dual vertical tails			
(a) Model launched nose up to simulate a whip stall			
Up	Neutral	147	Model made $\frac{3}{4}$ turn in tumble then trims in a glide
Neutral	Neutral	147	Model made $\frac{3}{4}$ to 1 turn in tumble then rolled about the longitudinal body axis
Down	Neutral	147	Model makes $\frac{1}{2}$ to $\frac{3}{4}$ turn in tumble then trims in a glide with rolling and yawing oscillations
(b) Model given an initial pitching rotation about a lateral axis			
Up	Neutral	147	Model makes $\frac{1}{2}$ turn then trims in a glide with yawing oscillations
Neutral	Neutral	147	Model makes $\frac{1}{2}$ to $\frac{3}{4}$ turn in tumble then glides out with rolling and yawing oscillations
Down	Neutral	147	Model makes $\frac{3}{4}$ turn in tumble then glides with slight rolling and yawing oscillations

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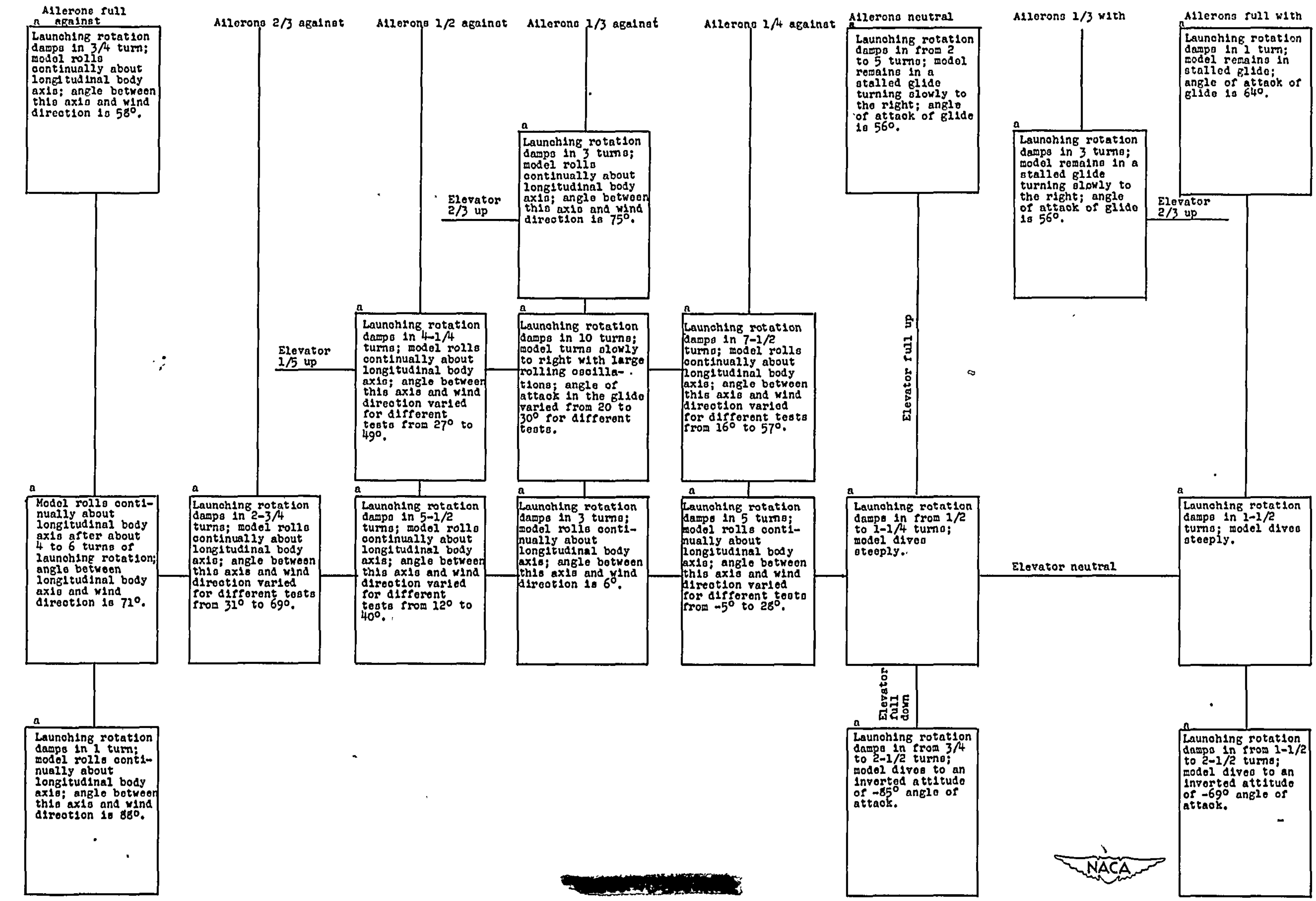
CHART 1.- FREE-SPINNING CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE CONSOLIDATED VULTEE MX-813 AIRPLANE WITH SINGLE VERTICAL TAIL

[Design gross weight (model loading 1 on table III and figure 4); landing gear retracted; cockpit closed; model launched in an erect attitude with the rudder fixed full with the direction of rotation; rotation to pilot's right]

[redacted]



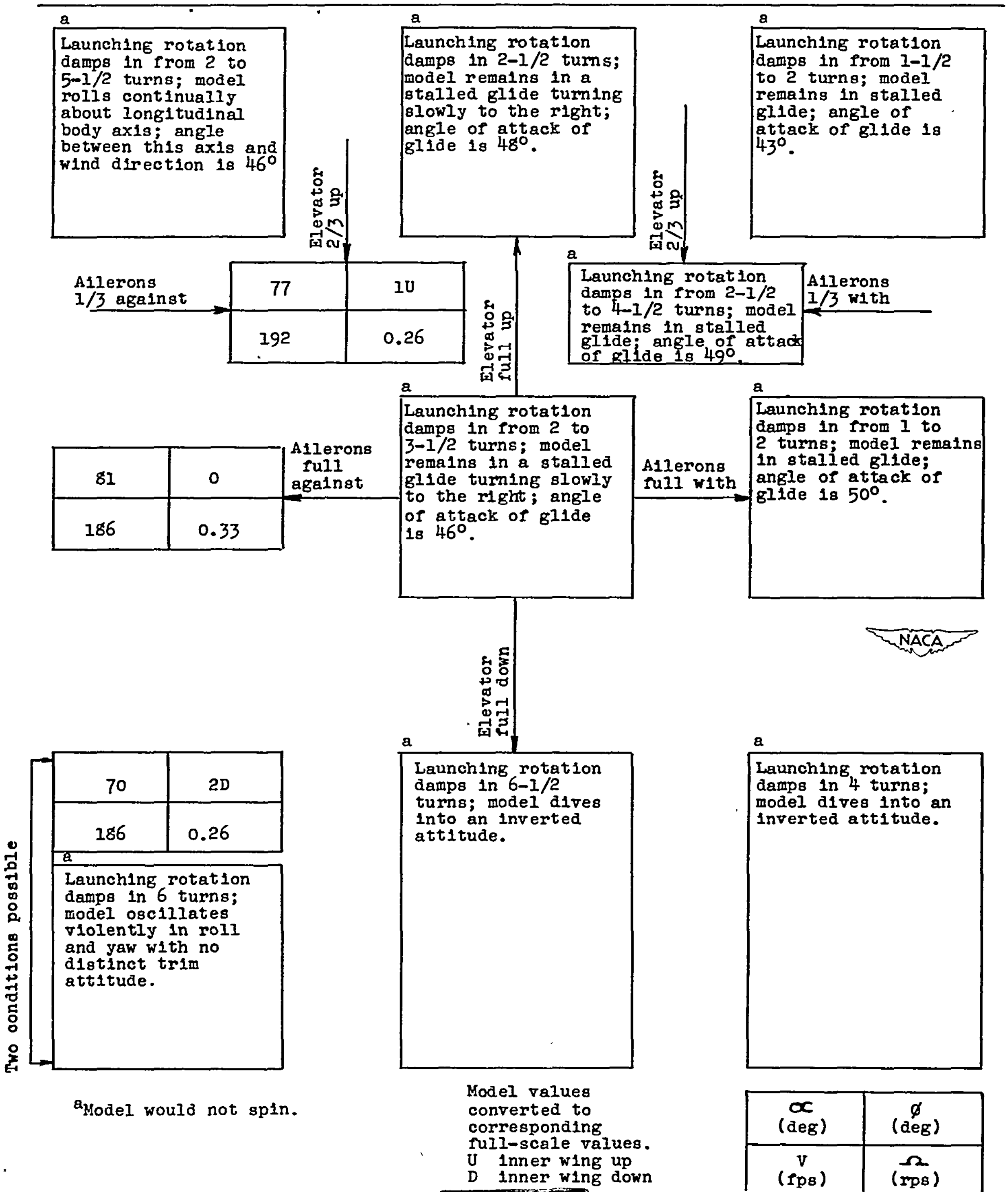
[a]Model would not spin.

[redacted]

[redacted]

CHART 2.- FREE-SPINNING CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE CONSOLIDATED VULTEE MX-813 AIRPLANE WITH THE SINGLE VERTICAL TAIL AND THE WING FILLETS INSTALLED

[Design gross weight (model loading 1 on table III and figure 4); landing gear retracted; cockpit closed; model launched in an erect attitude with the rudder fixed full with the direction of rotation; rotation to pilot's right]



[a]Model would not spin.

[redacted]

[redacted]

CHART 3.- FREE-SPINNING CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE CONSOLIDATED VULTEE MX-813 AIRPLANE WITH DUAL VERTICAL TAILS

[Design gross weight (model loading 6 on table III and figure 4); landing gear retracted; cockpit closed; model launched in an erect attitude with rudders fixed full with the direction of rotation; rotation into pilot's right]

Two conditions possible:

81	1U
198	0.36

Launching rotation damps in from 4 to 9-1/2 turns; model oscillates violently in roll and yaw going from erect to inverted attitude repeatedly.[a]

Elevator 2/3 up

[a] Launching rotation damps in from 2 to 4-3/4 turns; model remains in a stalled glide turning slowly to the right; angle of attack of glide is 61°.

[a] Launching rotation damps in from 1 to 2 turns; model pitched into a dive; angle of attack of dive is 17°.

Elevator 2/3 up

Ailerons 1/3 against

[a] Launching rotation damps in from 3-1/2 to 8 turns; model oscillates violently in roll and yaw going from erect to inverted attitudes repeatedly.

[a] Launching rotation damps in 1-1/4 turns; model remains in stalled glide; angle of attack of glide is 60°.

Ailerons 1/3 with

Elevator full up

[a] Launching rotation damps in from 10 to 15 turns; model oscillates violently in roll and yaw going from erect to inverted attitudes repeatedly.

Ailerons full against

[a] Launching rotation damps in from 4 to 7-1/2 turns; model dives steeply.

Ailerons full with

[a] Launching rotation damps in 2 turns; model dives steeply rolling with the ailerons.

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Elevator full down

[a] Launching rotation damps in 12 turns; model pitches to a steep attitude tending to go inverted.

[a] Launching rotation damps in 3 turns; model dives steeply tending to go inverted.

[a] Launching rotation damps in 4-1/2 turns; model dives steeply tending to go inverted.

[a]Model would not spin.

Model values converted to corresponding full-scale values.
U inner wing up
D [redacted]own

α (deg)	φ (deg)
V (fps)	Ω (rps)

[redacted]

[redacted]

CHART 4.- INVERTED SPINNING CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE MODEL OF THE CONSOLIDATED VULTEE MX-813 AIRPLANE WITH SINGLE VERTICAL TAIL

[Design gross weight (model loading 1 on table III and figure 4); landing gear retracted; cockpit closed; model launched in an inverted attitude with the rudders fixed full with the direction of rotation except as otherwise indicated; rotation to pilot's right; recoveries attempted by rudder reversal]

Top row, left (stick 1/3 right, 2/3 forward):

82	14D
186	0.38
1	

[a] Launching rotation damps in 4 turns; model rolls continually about longitudinal body axis; angle between this axis and wind direction is 80°.

Top row, center (stick full forward): [b] Launching rotation damps in 4-1/2 turns; model rolls erect then continues rolling about the longitudinal body axis or remains in a glide.

Top row, right (stick 1/3 left, 2/3 forward): [b] Launching rotation damps in 1-1/2 turns; model rolls erect and continues rolling about longitudinal body axis; angle between this axis and wind direction is about 49°.

Stick 2/3 forward (arrows to the top-row side boxes)

Stick forward (arrow to the top-row center box)

Middle row, left (stick 1/3 right):

76	14D
210	0.37

[a] Launching rotation damps in 3 turns; model rolls continually about longitudinal body axis; angle between this axis and wind direction is 55°.

Stick 1/3 right (arrow to the middle-row left box)

Middle row, right (stick 1/3 left): [b] Launching rotation damps in 3 turns; model rolls erect and continues rolling about longitudinal body axis; angle between this axis and wind direction is about 35°.

Stick 1/3 left (arrow to the middle-row right box)

Center row, left (stick right):

78	1D
186	0.40

[a] Launching rotation damps in 5 turns; model rolls continually about longitudinal body axis; angle between this axis and wind direction is 55°.

Stick right (Controls together) (arrow to the center-row left box)

Center (stick neutral): [b] Launching rotation damps in from 2 to 2-1/2 turns; model rolls erect then continues rolling about the longitudinal body axis or remains in a glide.

Stick left (Controls crossed) (arrow to the center-row right box)

Center row, right (stick left): [b] Launching rotation damps in 1-3/4 turns; model rolls erect and continues rolling about longitudinal body axis; angle between this axis and wind direction varying from 29° to 41° for different tests.

Stick back (arrow to the bottom-row center box)

Bottom row, left (stick right and back): [b] Launching rotation damps in 4-1/2 turns; model rolls erect remaining in a stalled glide with rolling and pitching oscillations; angle of attack in the glide varied from 16° to 60° during a test.

Bottom row, center (stick back): [b] Launching rotation damps in 1-3/4 turns; model rolls erect and continues rolling about the longitudinal body axis.

Bottom row, right (stick left and back): [b] Launching rotation damps in 1-1/2 turns; model rolls erect and continues rolling about longitudinal body axis; angle between this axis and wind direction is about 54°.

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[a]Model launched with rudder fixed full against the direction of rotation.
[b]Model would not spin.

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

Key (layout of the value boxes):

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

[redacted]

[redacted]

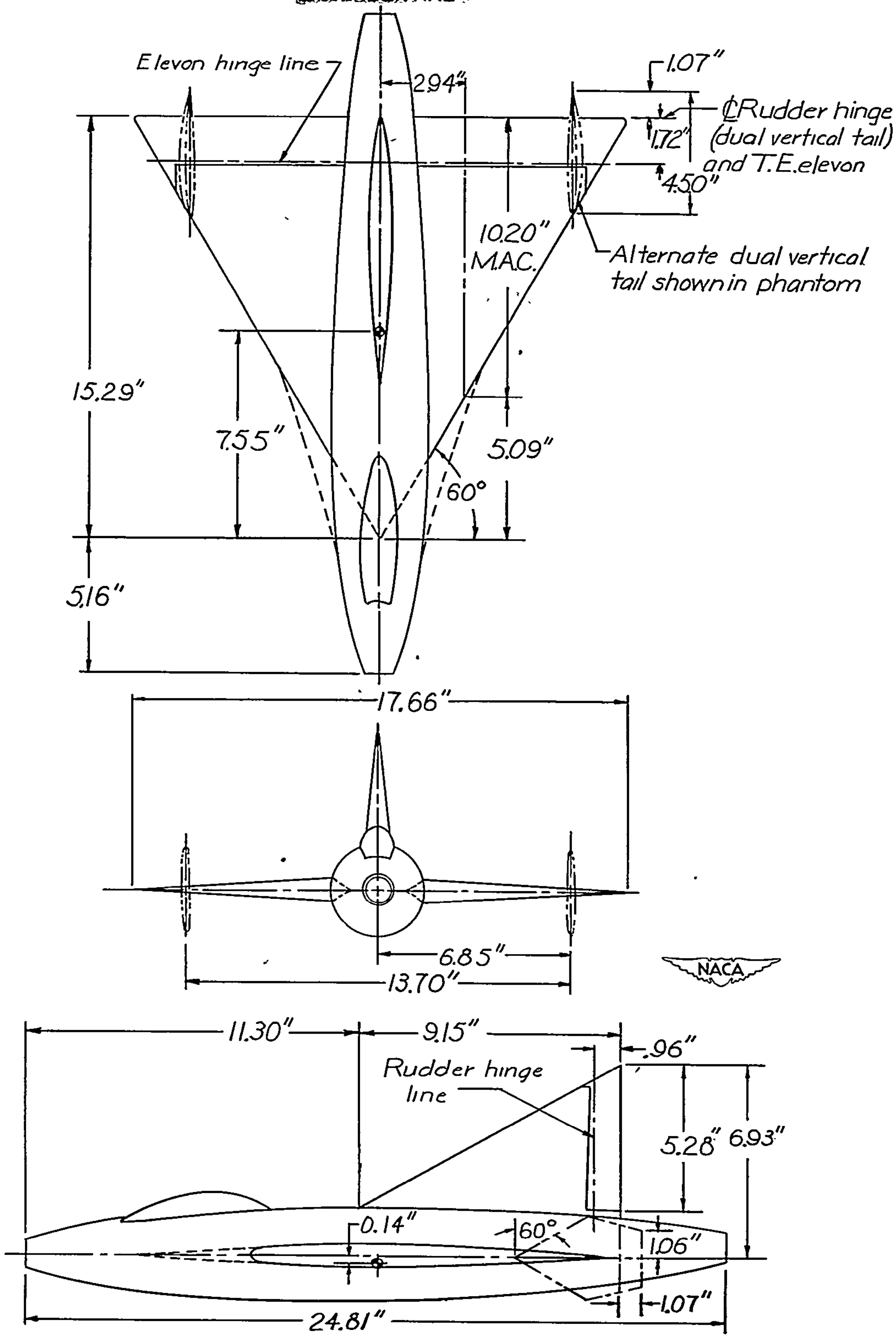

Figure 1.- Drawing of a $\frac{1}{20}$-scale model of the Consolidated Vultee MX-813 airplane as tested in the free-spinning tunnel. Center of gravity is shown for the design gross weight loading.

[redacted]

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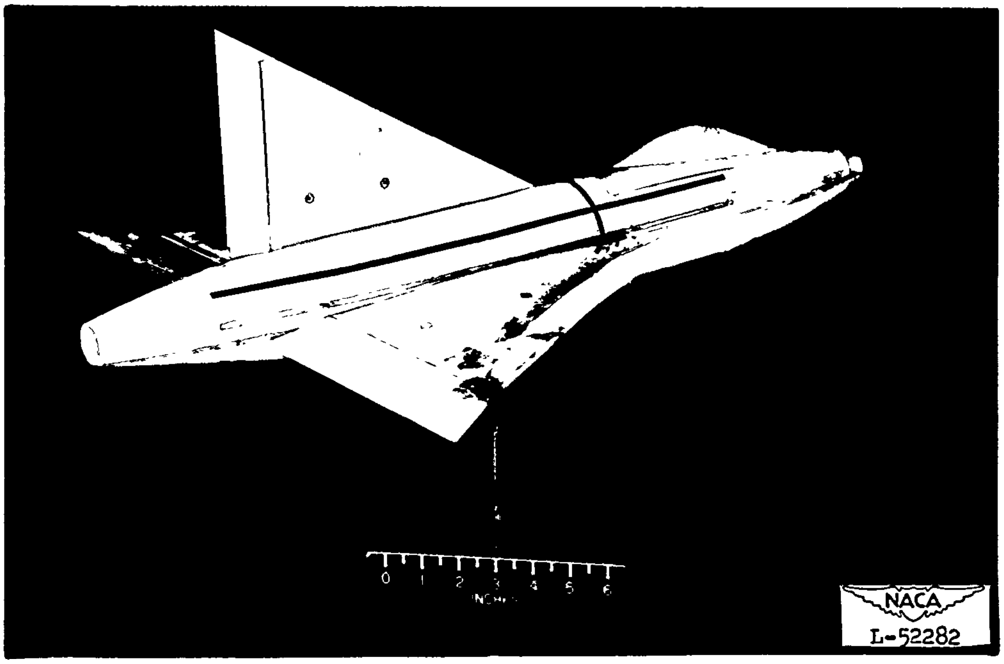
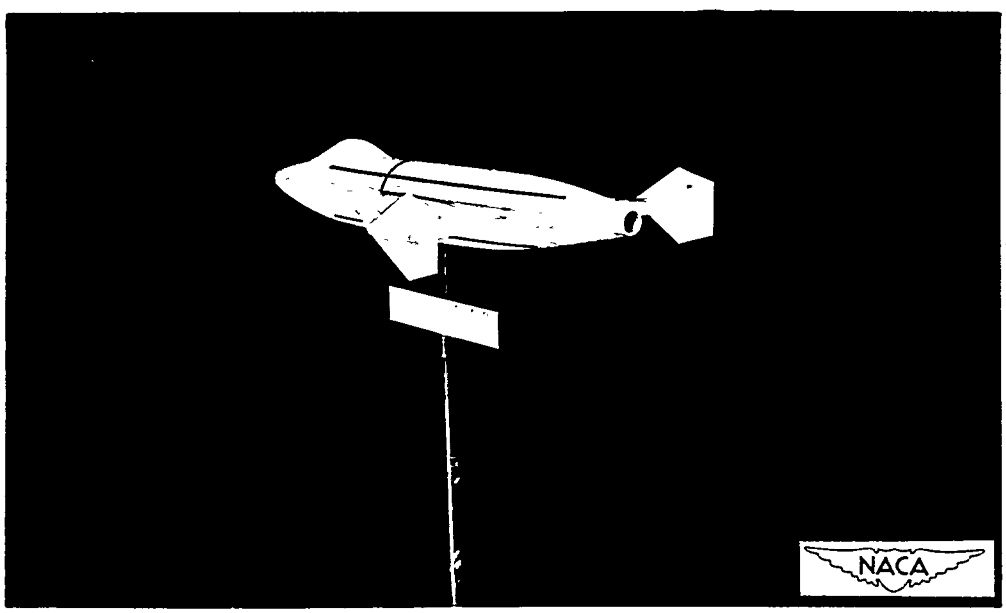


(a) Single-vertical-tail configuration.



(b) Dual-vertical-tail configuration.

Figure 2.- Photographs of the $\frac{1}{20}$-scale model of the Consolidated Vultee MX-813 airplane.

[redacted]

[redacted]

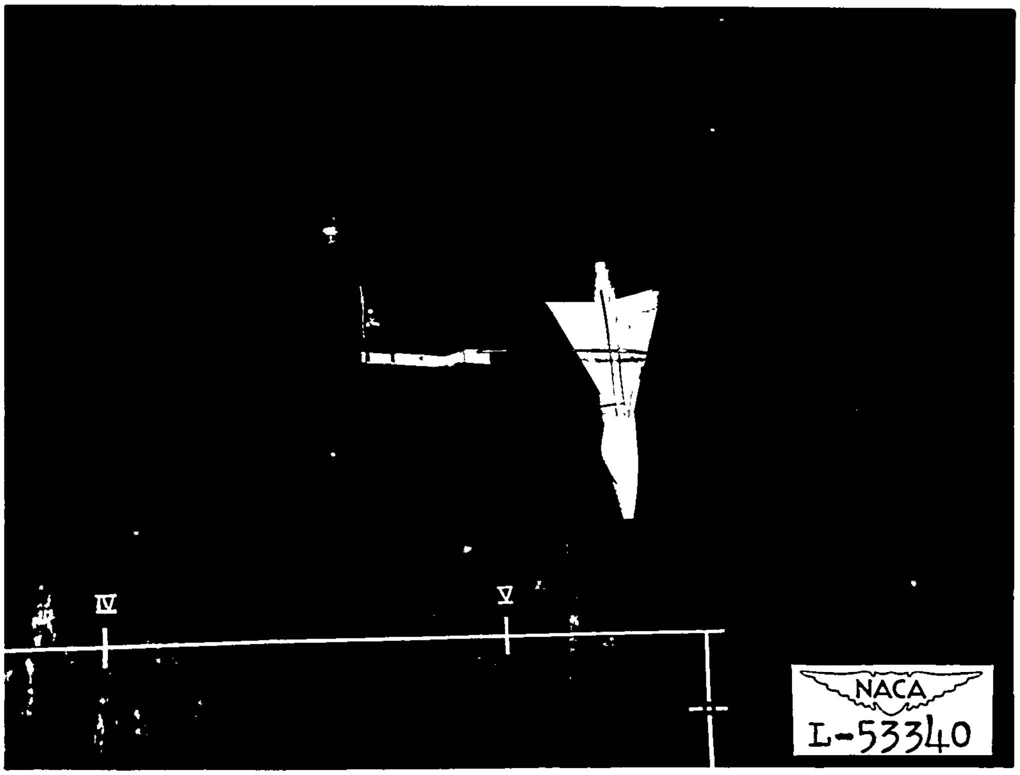


Figure 3.- The $\frac{1}{20}$-scale model of the Consolidated Vultee MX-813 airplane mounted for longitudinal-trim tests in the Langley 20-foot spin tunnel.

[redacted]

[redacted]

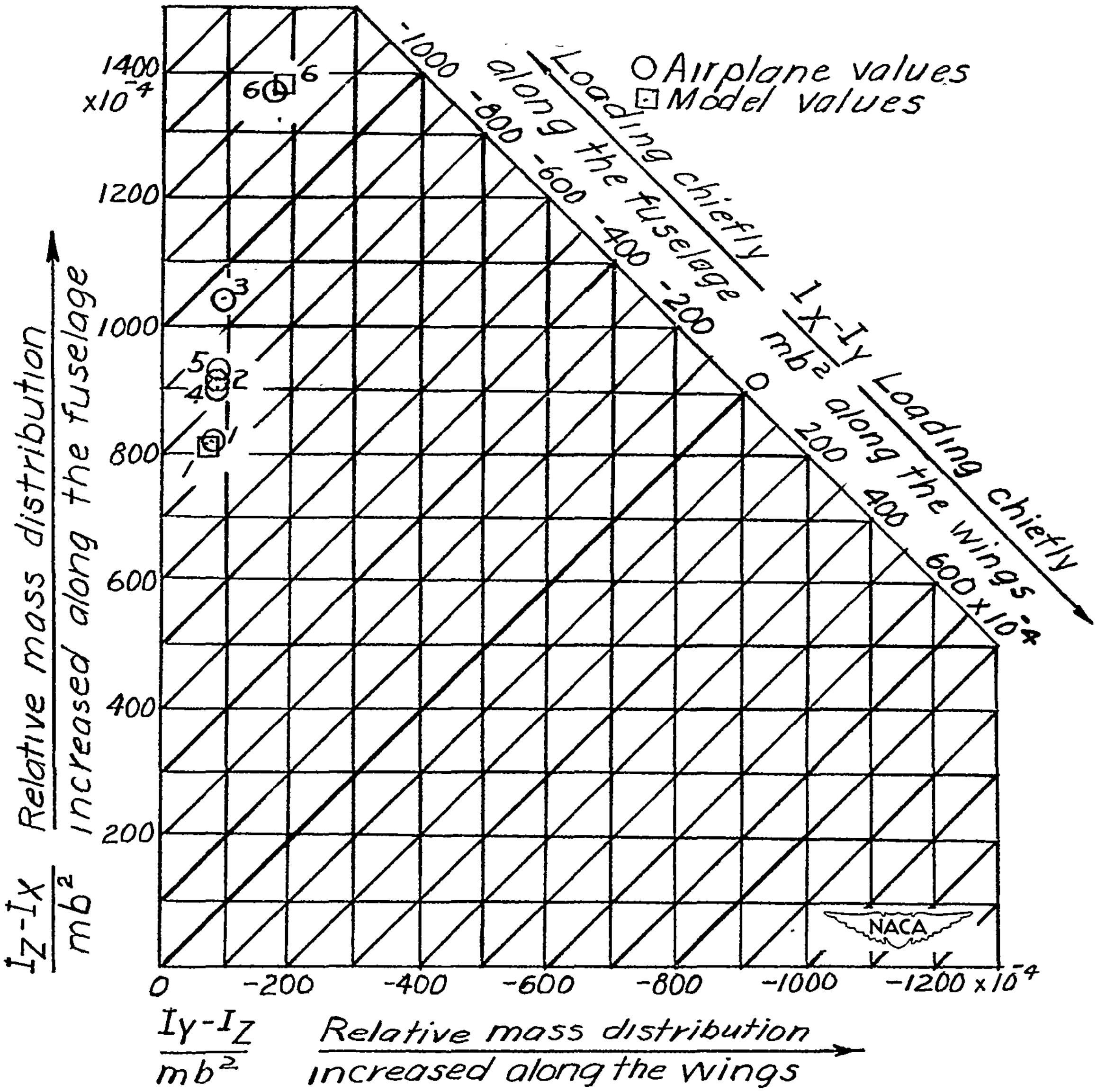


Figure 4.- Inertia parameters for loadings possible on the Consolidated Vultee MX-813 airplane and for loadings tested on the $\frac{1}{20}$-scale model. (Points are for loadings listed in table III.)

[redacted]

[redacted]

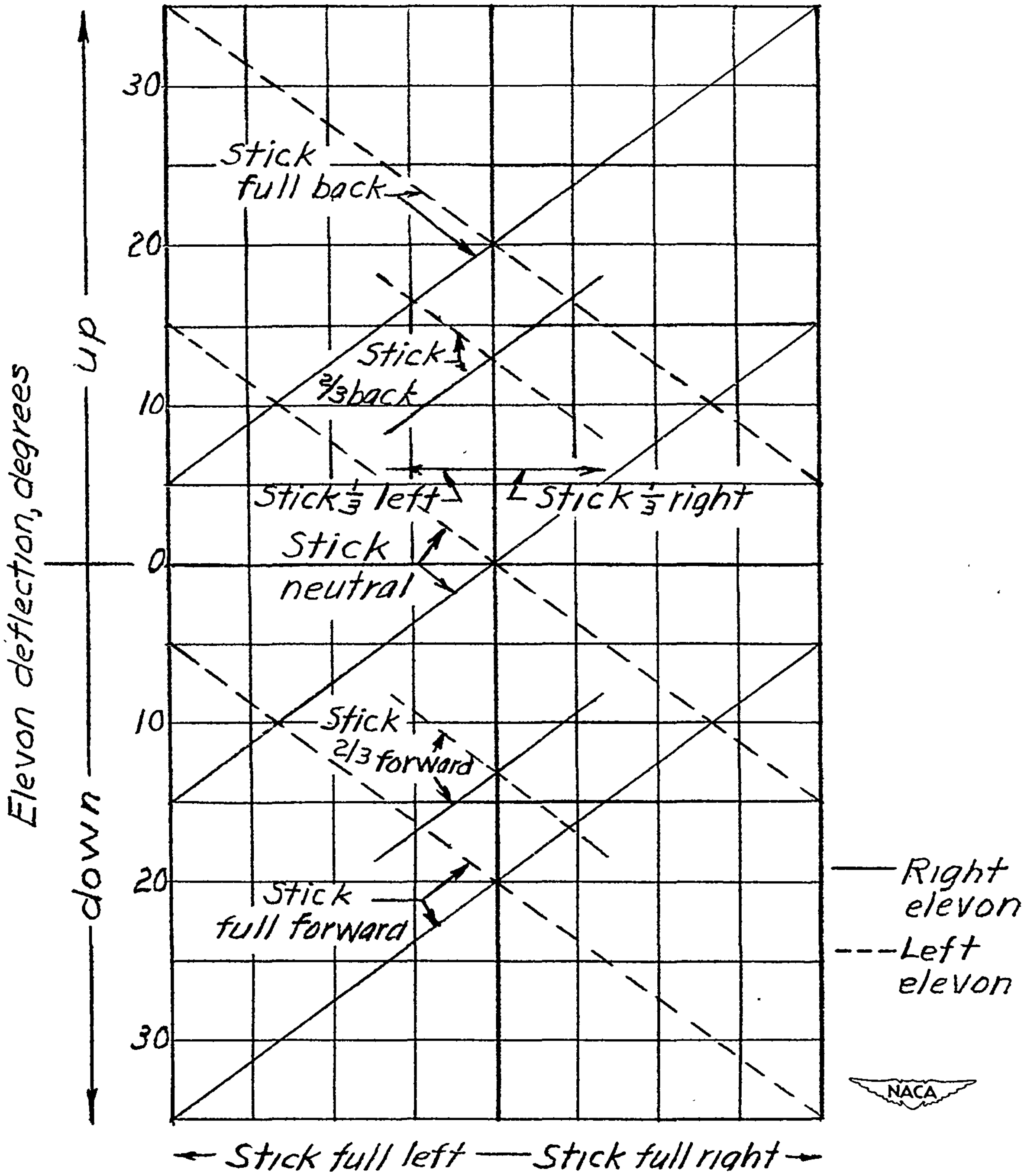
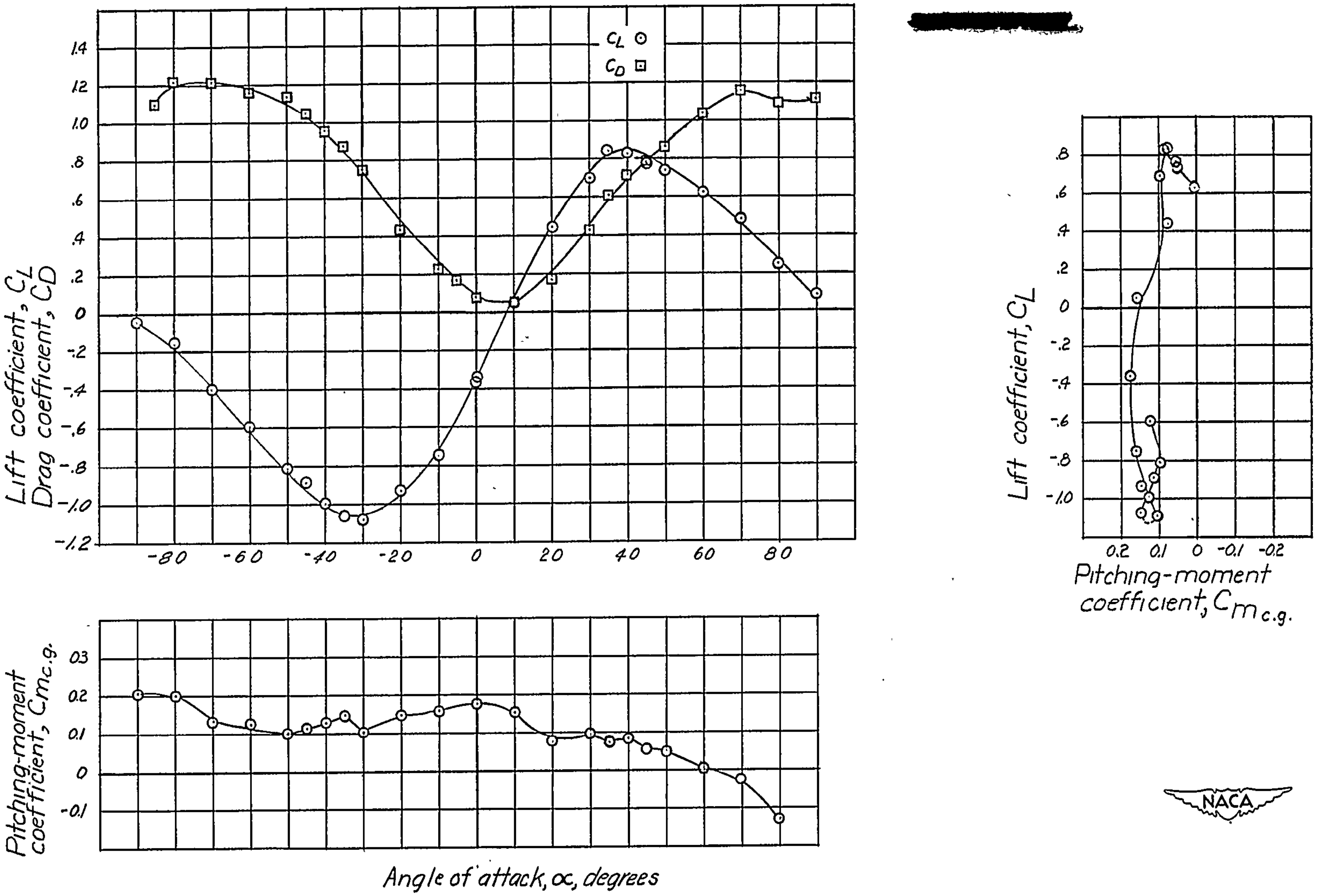


Figure 5.- Elevon deflections used on the $\frac{1}{20}$-scale model of the MX-813 airplane for various control stick positions for the single- or dual-vertical-tail configurations. [redacted]

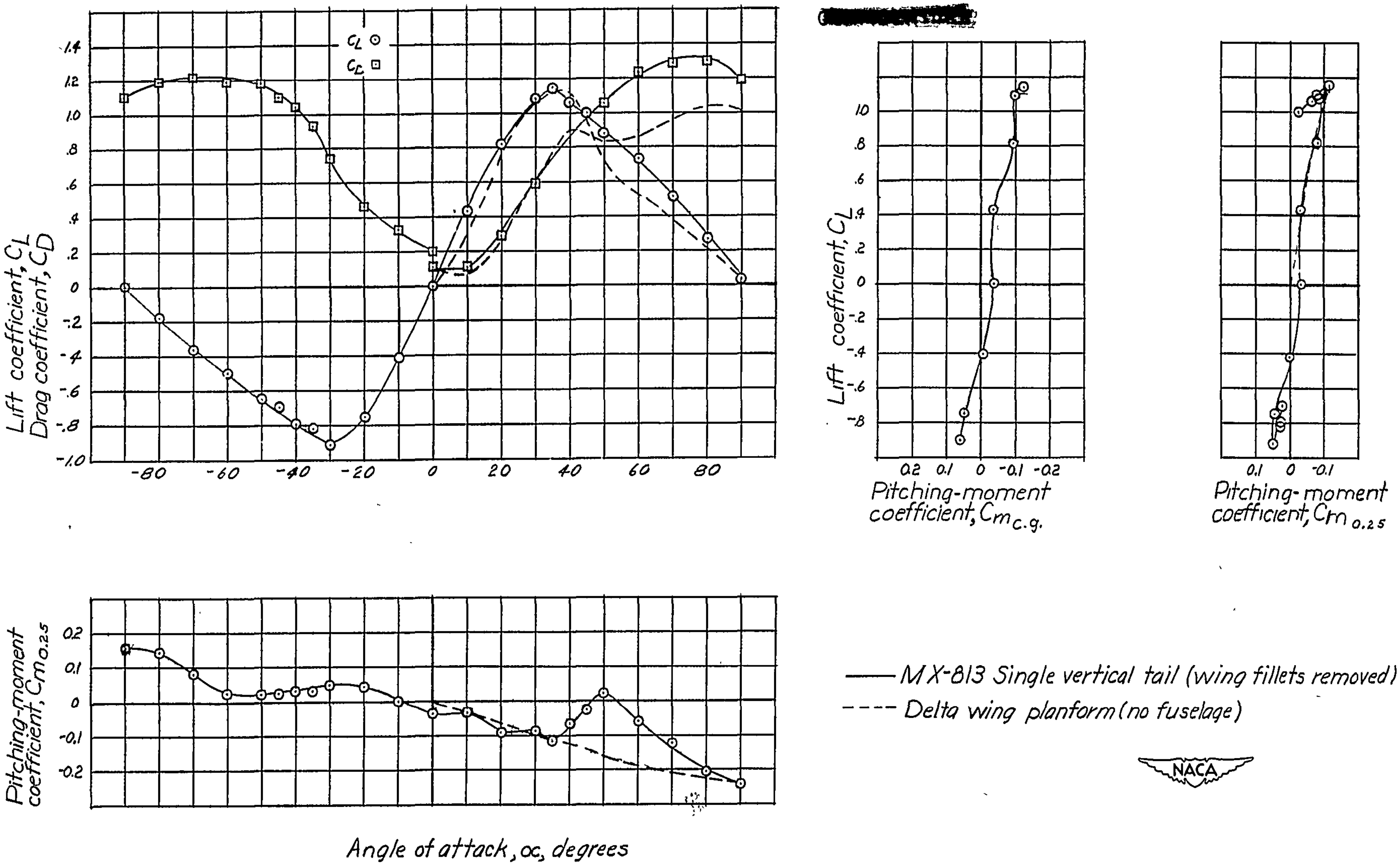
[redacted]



(a) Elevator up ($\delta_e = -20^{\circ}$).

Figure 6.- Aerodynamic characteristics of the $\frac{1}{20}$-scale model of the Consolidated Vultee MX-813 airplane (wing fillets removed) with single vertical tail. $\psi = 0^{\circ}$; $\delta_r = 0^{\circ}$; $\delta_a = 0^{\circ}$.

[redacted]



(b) Elevator neutral ($\delta_e = 0^{\circ}$).

Figure 6.- Continued.

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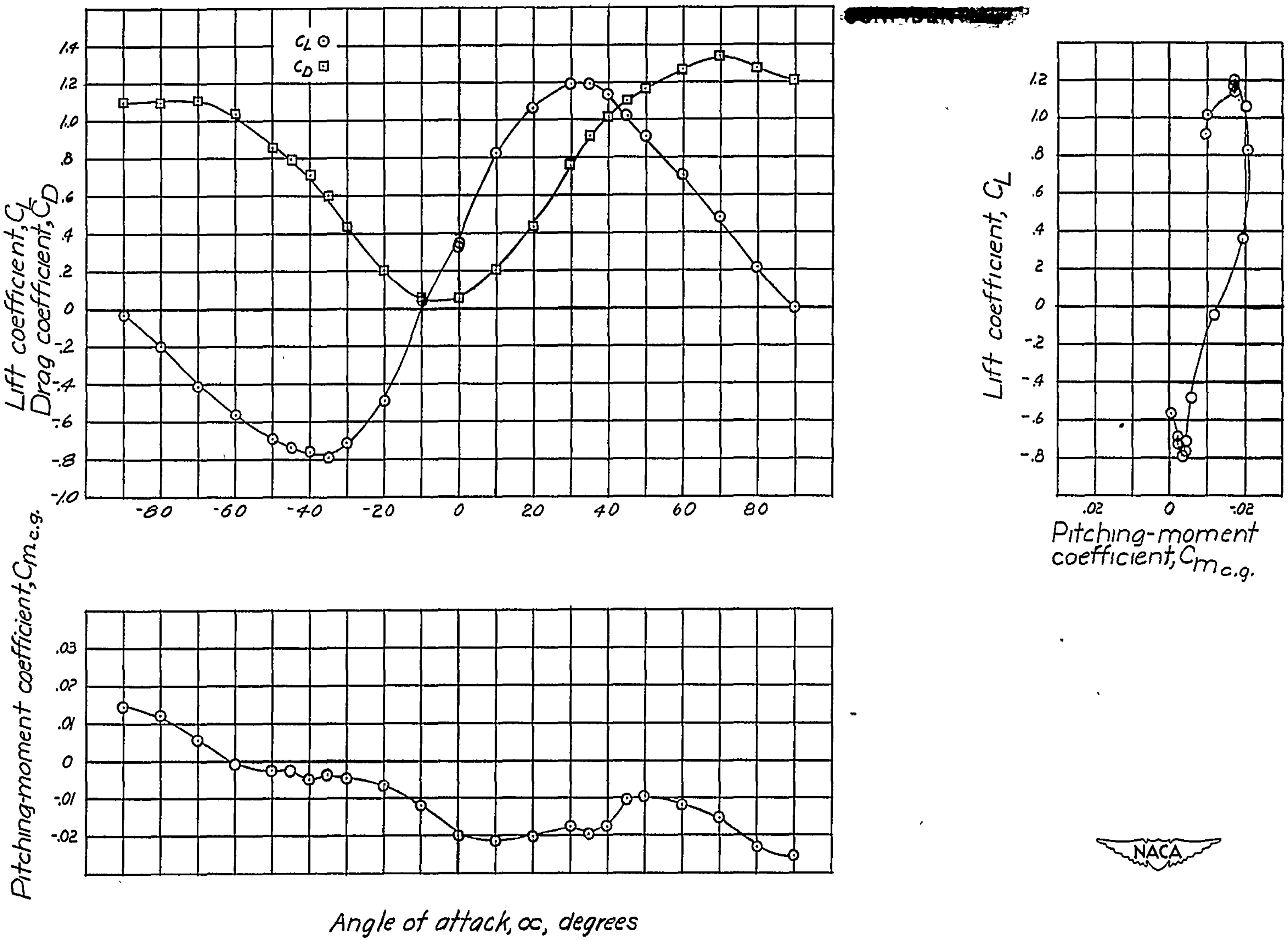
[redacted]



(c) Elevator down ($\delta_e = 20^\circ$).

Figure 6.- Continued.

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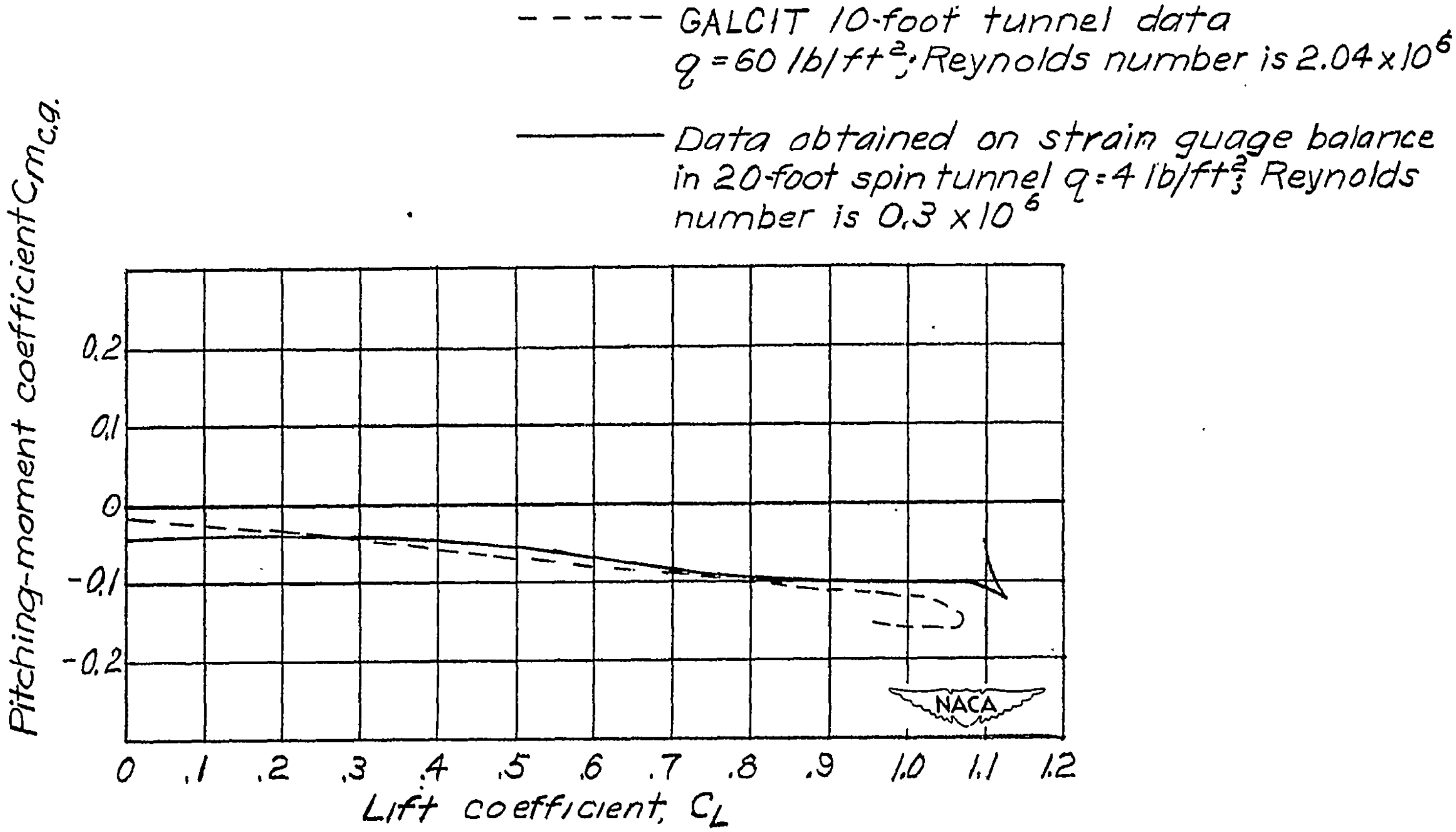

Figure 6(d).- Comparison of pitching-moment data for the $\frac{1}{20}$-scale spin model and a $\frac{1}{12.78}$-scale wind-tunnel model tested in the GALCIT 10-foot wind tunnel. $\psi = 0^{\circ}$; $\delta_e = 0^{\circ}$; $\delta_a = 0^{\circ}$; $\delta_r = 0^{\circ}$.

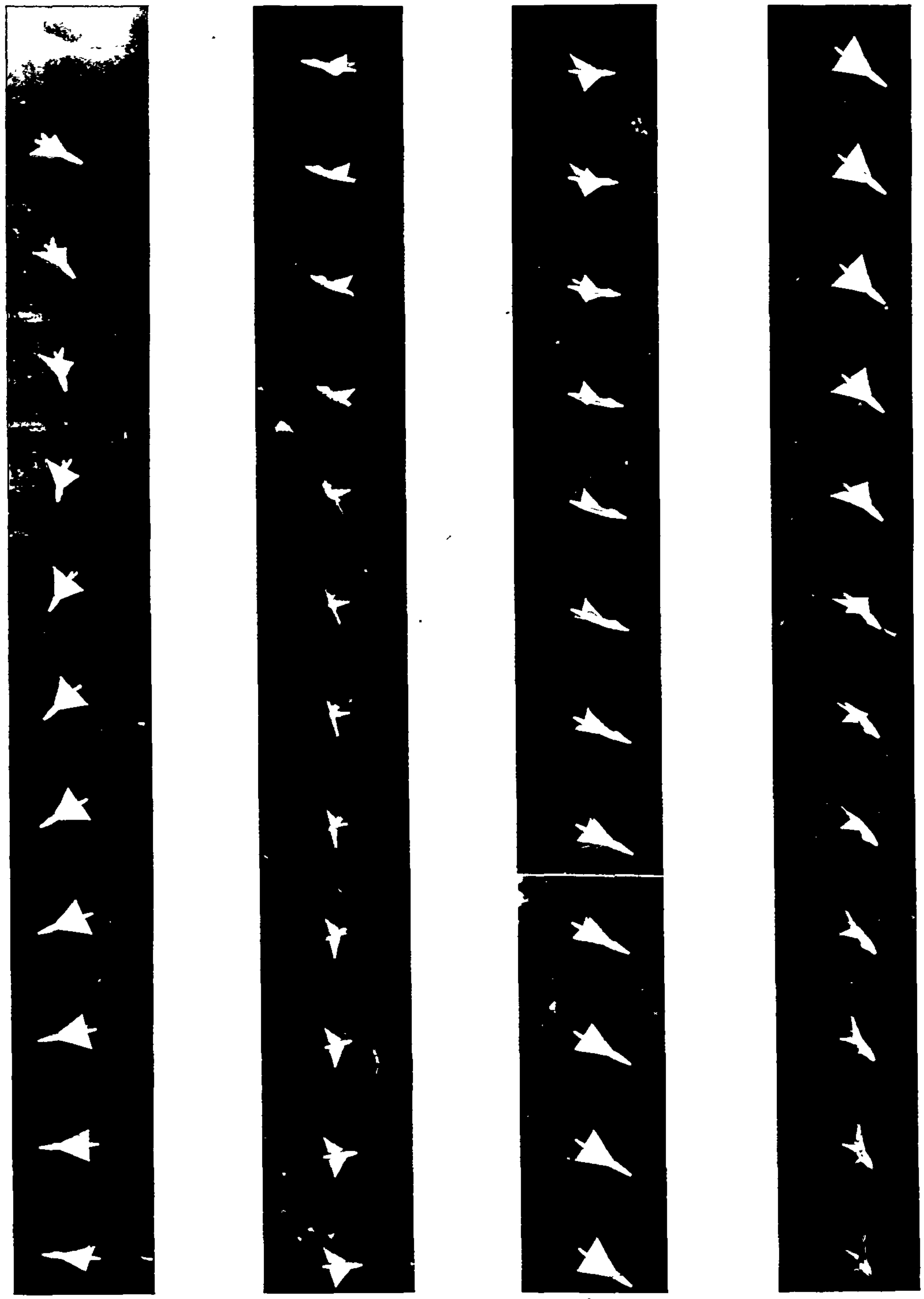

Figure 7.- Typical motion of the $\frac{1}{20}$-scale model of the MX-813 airplane with the ailerons set against the spin, following launching with spinning rotation. Camera speed 64 frames per second.

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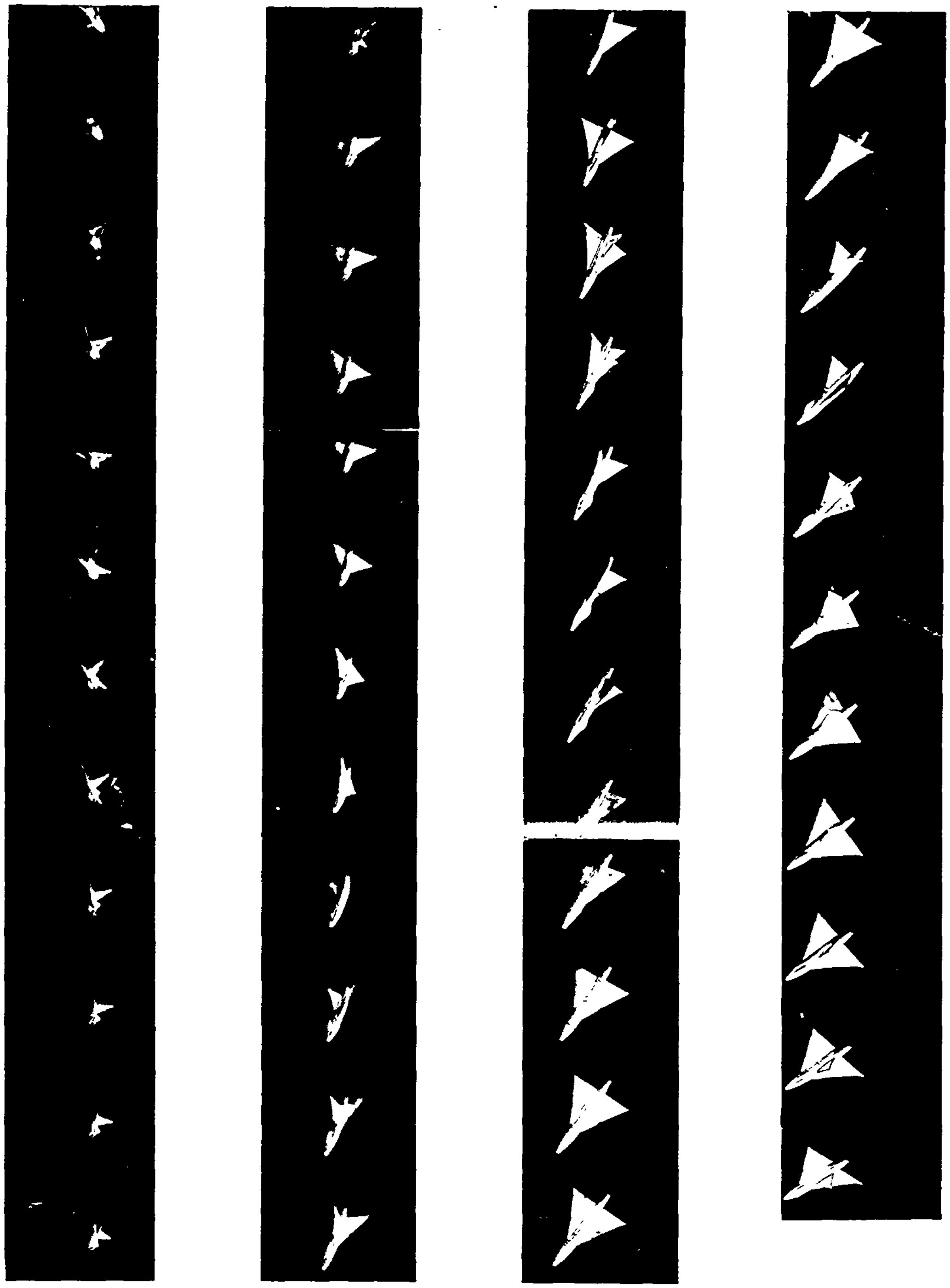

Figure 7.- Concluded.

[redacted]