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RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

SUPPLEMENTARY INVESTIGATION TO DETERMINE THE EFFECTS OF CENTER-OF-GRAVITY POSITION ON THE SPIN, LONGITUDINAL-TRIM, AND TUMBLING CHARACTERISTICS OF A $\frac{1}{20}$-SCALE MODEL OF THE CONSOLIDATED VULTEE 7002 AIRPLANE

(FLYING MOCK-UP OF XF-92)

By

Walter J. Klinar and Ira P. Jones, Jr.

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

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SUPPLEMENTARY INVESTIGATION TO DETERMINE THE EFFECTS OF CENTER-OF-GRAVITY POSITION ON THE SPIN, LONGITUDINAL-TRIM, AND TUMBLING CHARACTERISTICS OF A $\frac{1}{20}$-SCALE MODEL OF THE CONSOLIDATED VULTEE 7002 AIRPLANE

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SUMMARY

A supplementary wind-tunnel investigation has been conducted to determine the effect of rearward positions of the center of gravity on the spin, longitudinal-trim, and tumbling characteristics of the $\frac{1}{20}$-scale model of the Consolidated Vultee 7002 airplane equipped with the single vertical tail. A few tests were also made with dual vertical tails added to the model. The model was ballasted to represent the airplane in its approximate design gross weight for two center-of-gravity positions, 30 and 35 percent of the mean aerodynamic chord. The original tests previously reported were for a center-of-gravity position of 24 percent of the mean aerodynamic chord.

The spin and longitudinal-trim results obtained for the present investigation were generally similar to those obtained originally in that the model generally did not spin but demonstrated a tendency to trim at high stalled angles of attack. For the current tests, spins were obtained only when the ailerons were placed against the spin. Though the spins could not be terminated by reversing the rudder, moving the ailerons to full with the spin was effective in stopping the spin rotation; however, the model trimmed at high stalled angles of attack after the cessation of the spin rotation unless the elevator was down. Brief tests performed with the center of gravity positioned at 30 percent of the mean aerodynamic chord showed that by adding the dual vertical tails to the wing tips, the spin obtained could be terminated by reversing only the rudders. As was the case when the single vertical tail alone was installed on the model,

stalled trim attitudes were obtained after the termination of the spin rotation. It was necessary to move the elevator from up to 10° down to pitch the model out of its stalled attitudes when the center of gravity was at 30 percent of the mean aerodynamic chord; when the center of gravity was at 35 percent of the mean aerodynamic chord, rapid movement of the elevator from up to 35° down was required to enable the model to recover from the stalled glides.

The model tumbled when the center of gravity was at 30 or 35 percent of the mean aerodynamic chord. The results of the investigation indicated that reversal of the elevator would probably not be effective in terminating the rotation. Analysis of the model motion indicated that the accelerations encountered in a tumble of the 7002 airplane might be dangerous to a pilot. The results of the investigation indicate that limitation of the rearward position of the center of gravity to about 25 percent mean aerodynamic chord will prevent the 7002 airplane from tumbling.

INTRODUCTION

Subsequent to the issuance of reference 1, additional tests have been made in the Langley 20-foot free-spinning tunnel on a $\frac{1}{20}$-scale model of the Consolidated Vultee 7002 airplane to determine the manner in which the spin, longitudinal-trim, and tumbling characteristics of the model would be affected by moving the center of gravity rearward from the original normal position. The current spin-tunnel investigation was performed because it was indicated that the center of gravity on the 7002 airplane would be at a position farther rearward than had originally been anticipated.

The investigation for the most part, was conducted with the single vertical tail installed on the model. The model was ballasted so that its moments of inertia corresponded to those at its original design gross-weight loading and two center-of-gravity positions were tested, 30 and 35 percent of the mean aerodynamic chord. In addition, brief spin tests were conducted with the dual vertical tails installed in conjunction with the single vertical tail when the center of gravity was positioned at 30 percent of the mean aerodynamic chord.

SYMBOLS AND COEFFICIENTS

b	wing span, feet
S	wing area, square feet

$\bar{c}$	mean aerodynamic chord
$x/\bar{c}$	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 $(m/\rho Sb)$
α	angle of attack, degrees. (For the spin data presented on the charts, α is the angle between fuselage reference line and vertical and is approximately equal to the absolute value of the angle of attack)
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
C_m	pitching-moment coefficient $(M/qS\bar{c})$
M	pitching moment about center of gravity of airplane
ψ	angle of yaw about 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 7002 airplane used for the investigation reported in reference 1 was used in the current investigation. A drawing of the model in the clean condition is shown in figure 1. The dimensional characteristics of the airplane as represented by the model are given in table I. There were no wing fillets on the model.

As indicated in reference 1, lateral and longitudinal control are combined in one pair of controls called elevons. Longitudinal control is obtained by deflection of the elevons together, and lateral control is obtained by differential deflection of the elevons. Hereinafter, elevon deflections for longitudinal and lateral control will be referred to, for simplicity, as elevator and aileron deflections, respectively.

Wind Tunnel and Testing Technique

Tests were performed in the Langley 20-foot free-spinning tunnel. The testing technique applied and methods for determining the spin data were essentially the same as those reported in reference 2. For some of the current tests, however, recovery from the spin was attempted by moving the ailerons from their original against-the-spin setting to their maximum deflection in the opposite direction (full with the spin). Provision was also made for movement of the elevator down while the model was in free flight in the tunnel.

The tumbling procedure was similar to that given in reference 1 in that the model was launched in a simulated whip-stall condition and also with forced pitching rotation (both positive and negative). As is explained in reference 1, if the model tumbles when launched in either manner, it is taken as an indication that the corresponding airplane might tumble, although the corresponding airplane would be more likely to tumble if the model began tumbling when launched with no pitching rotation.

The precision of the test results and the limits of accuracy of the measurements of the mass characteristics are considered the same as those reported in reference 1.

Test Conditions

The conditions tested on the model are listed in table II. The mass characteristics of the model are listed in table III and the inertia mass parameters for the model as tested are given in both table III and figure 2.

The force-test data presented were obtained from reference 1.

The maximum normal control deflections used in the current tests were the same as those utilized during the original investigation:

Rudder, degrees	
Right	30
Left	30
Elevons, degrees	
As elevators	
Up	20
Down	20
As ailerons	
Up	15
Down	15

Figure 3 shows the angular deflections of the elevons plotted against stick deflection.

RESULTS AND DISCUSSION

Spin Tests

Single-vertical-tail configuration.- The results of the spin investigation for the model with the single-vertical-tail configuration loaded to simulate the 7002 airplane with the center of gravity at 30 and 35 percent of the mean aerodynamic chord are presented in charts 1 and 2, respectively. These results were generally similar to those obtained when the center of gravity was at approximately 24 percent of the mean aerodynamic chord (reported in reference 1) in that the model generally did not spin but demonstrated a tendency to trim at high stalled angles of attack after the imposed launching rotation was expended. Charts 1 and 2 show that the model spun only when the ailerons were placed at about 1/3 against the spin when the center of gravity was at 30 percent of the mean aerodynamic chord and when the ailerons were either partially or fully against the spin when the center of gravity was at 35 percent of the mean aerodynamic chord. As is indicated in charts 1 and 2, when the center of gravity was at 30 percent of the mean aerodynamic chord and the elevator was set to 10° down the model no longer trimmed in a flat glide but entered a dive, and when the center of gravity was at 35 percent of the mean aerodynamic chord and the elevator was set to 60° down, the model pitched inverted. Rudder reversal was ineffective in terminating the spin rotation but the results of the tests presented on chart 1 indicate that the spin rotation could be terminated by movement of the ailerons to full with the spin. After the cessation of the spin rotation, however, the results indicate that the model would generally trim at flat stalled angles of attack.

Results of tests performed to determine the effect of dynamic elevator movement in terminating the stalled glides that were obtained after the spin rotation ceased are presented in table IV. When the center of gravity was at 30 percent of the mean aerodynamic chord there was little effect of the dynamic elevator movement in that it was necessary to move the elevator from up to 10° down to pitch the model out of its stalled attitude. When the center of gravity was at 35 percent of the mean aerodynamic chord, however, rapid movement of the elevator from up to 35° down pitched the model inverted, indicating a somewhat beneficial effect of dynamic elevator movement for this position of the center of gravity. (Reference 1 indicates that when the center of gravity was at about 24 percent of the mean aerodynamic chord, moving the elevator slightly down beyond neutral enabled the model to pitch into a dive.) As is indicated in table IV, when the center of gravity was at 35 percent of the mean aerodynamic chord and the elevator was reversed for recovery from the stalled glides, the model oscillated in pitch before finally pitching inverted, the pitch oscillations being quite large and the final pitch to an inverted attitude occurring very rapidly. This maneuver would certainly be confusing to a pilot and also dangerous inasmuch as it appears that when it becomes necessary to move the elevator down much beyond neutral to effect recovery from the stalled glides there exists the possibility that the corresponding airplane might pitch inverted and trim on its back.

Addition of dual-vertical tails.- To improve the spin recovery characteristics of the model by normal usage of the controls, the dual vertical tails were added at the wing tips, and the center vertical tail was retained. The tests were conducted with the center of gravity positioned at 30 percent of the mean aerodynamic chord and the test data are presented in chart 3. Chart 3 shows that although the dual vertical tails contributed sufficient damping to prevent the attainment of a condition of spin equilibrium when the ailerons were placed either partially or fully against the spin, the model now tended to spin at the normal spin-control configuration. To expedite tests, recoveries were not attempted from this spin by movement of the rudders, but the model was launched into the tunnel with the rudders merely set against the spin. Inasmuch as the imparted launching rotation damped out rapidly with the rudders set against the spin, this was taken as an indication that the spin rotation would also have been terminated rapidly had all three rudders been reversed from with to against the spin. The flat stalled trim attitudes that were obtained after the cessation of the spin rotation when only the single vertical tail was installed were also obtained for this configuration of the model.

Static-Force Tests and Scale Comparison

A comparison plot of the pitching-moment characteristics of the model for center-of-gravity positions of approximately 24, 30, and 35 percent of the mean aerodynamic chord is shown in figure 4. This plot was derived from the force data presented in reference 1 for the center of gravity at about 24 percent of the mean aerodynamic chord. As was indicated in reference 1, the force data is in general agreement with the results of the dynamic-model tests as regards prediction of model trim attitudes for various elevator settings. In order to determine the limiting center of gravity and elevator positions required to prevent trim at stalled positive angles of attack, cross plots of the pitching-moment data presented in figure 4 were made and are presented in figure 5. Figure 5 shows that when the center of gravity is at about 24 and 30 percent of mean aerodynamic chord, elevator deflections somewhat in excess of 2° down and 17° down, respectively, should effectively terminate a stalled glide. Extrapolation of the curve for the center of gravity at 35 percent of the mean aerodynamic chord shows that an elevator deflection somewhat greater than 30° down would be required to pitch the model out of a stalled attitude. In addition it is shown in figure 5 that if the center of gravity is maintained somewhat forward of 31 percent of the mean aerodynamic chord, normal full down movement of the elevator (20° down) should be effective in unstalling the model.

A comparison plot of the pitching-moment data obtained on the $\frac{1}{20}$-scale spin model of the 7002 airplane, a $\frac{1}{12.8}$-scale model of the 7002 airplane tested at GALCIT, and a full-scale 7002 airplane tested at Ames Aeronautical Laboratory is shown in figure 6. It will be noted that all three curves are generally similar below the stall and that they all break in the unstable direction at an angle of attack of about 35°. Unfortunately no data are available for the $\frac{1}{12.8}$-scale model and the full-scale 7002 airplane for angles of attack above 40°, but inasmuch as the pitching-moment curves for all three versions of the 7002 airplane are generally similar below about 40° angle of attack, it appears possible that they may be similar throughout the whole angle-of-attack range. Based on this assumption it might be expected that the trim attitudes experienced by the $\frac{1}{20}$-scale spin model would indicate rather closely the trim conditions that may be expected on the full-scale 7002 airplane. In this connection it might also be mentioned that the results of previous longitudinal-trim tests performed in the spin tunnel on a 0.059-scale model of an airplane did indicate general agreement between the trim attitudes experienced by the model and the full-scale airplane (reference 3).

Tumbling

The results of the present tumbling investigation are presented in table V. Results of previous tumbling tests presented in reference 1 showed that the model would not tumble when the center of gravity was at about 24 percent of the mean aerodynamic chord.

Although the tumbling tendencies of the model were somewhat greater when the center of gravity was at 35 percent of the mean aerodynamic chord than when the center of gravity was at 30 percent of the mean aerodynamic chord, the results show the model to be capable of tumbling regardless of elevator setting, for either position of the center of gravity. The tumbling motion either consisted of a pitching motion about the Y-axis (fig. 7), or of a pitching motion combined with yawing and rolling. The most persistent of these latter motions was a tumble with superimposed rolling but the model also cartwheeled at times and at times experienced only a rolling motion (two sequences shown in fig. 8).

From the results of the model tests it appears that for rearward positions of the center of gravity, if the 7002 airplane is stalled with its nose near the vertical or if it is forced into a nose-up attitude by a strong gust, it may tumble. The tumble may consist either of a pitching motion about the Y-axis or a motion consisting of combination of pitching, yawing, and rolling as has just been discussed. Reversal of the elevator will probably be ineffective in terminating the developed tumble. It appears from the results of reference 1 and from the present investigation that it will be necessary to limit the center of gravity to approximately 25 percent of the mean aerodynamic chord to insure that the 7002 airplane does not tumble.

An analysis of the motion of the 7002 model during tumbles was made in order to compute the instantaneous transverse and normal accelerations acting at a pilot's head during a tumble. The centripetal acceleration and the tangential acceleration due to changes in rate of rotation were considered in these computations. The model was assumed to descend along a straight path and to tumble about its center of gravity. A tabulation of the computed accelerations for three separate tumbles when the center of gravity was at 35 percent of the mean aerodynamic chord is shown in table VI. These accelerations are considered to be indicative of the accelerations that may exist during tumbles of the 7002 airplane. Table VI shows that the accelerations vary rapidly in magnitude and direction and that the most critical accelerations are a negative normal acceleration (pushing the pilot upward in his seat) of 9.6g and a transverse acceleration (pushing the pilot forward in his seat) of the order of 16.7g. Since the model was approximately level when these accelerations occurred, adding the effects of gravity (1 g) to these accelerations causes the negative normal acceleration to be reduced by 1 g, whereas the transverse acceleration is unaffected.

Inasmuch as the peak accelerations are of such short duration, it is not known whether they will be harmful to a pilot, but the available information on the subject indicates that the accelerations experienced may be dangerous. Reference 4, issued in 1937, indicates that there is little time lag in negative normal accelerations and that accelerations of -3g will cause symptoms of concussion, whereas accelerations of the order of -5g may result in massive cerebral hemorrhages and death. Reference 4 further indicates that transverse accelerations are well tolerated up to 12g, the principal physiological effect of high transverse g being a compression of the framework of the body tending to induce forced expiration and resulting in an involuntary holding of the breath. More recent experiments (references 5 and 6) have indicated that normal accelerations of -3.6g lasting for 7 seconds, -4g lasting for 0.3 second, -7g lasting for 0.17 second, and -11g lasting for 0.003 second have been demonstrated by human subjects to be tolerable. A comparison plot of the accelerations computed to exist at a pilot's head during the most critical portion of a tumble (that is, where the highest negative g's are experienced) and a plot derived from references 5 and 6 showing the negative g's that have been demonstrated to be tolerable is shown in figure 9. Figure 9 shows that excessive accelerations may be experienced. In addition, computations made to determine the head venous pressures that may be experienced by a pilot in a tumble show that the pressures momentarily exceed the danger limit indicated in reference 7. Inasmuch as the dangerous venous pressures last for only short periods, however, there is some question as to their harmful effects. On the basis of these references it may be concluded that the negative normal accelerations encountered in a tumble might be dangerous to a pilot, and, also, that he might suffer harmful effects from the high transverse g.

CONCLUSIONS

Based on the spin-tunnel test results of the $\frac{1}{20}$-scale model of the Consolidated Vultee 7002 airplane equipped with a single vertical tail with the center of gravity at 30 and 35 percent of the mean aerodynamic chord, the following conclusions are made:

1. The spin and longitudinal-trim characteristics of the airplane when the center of gravity is at 30 or 35 percent of the mean aerodynamic chord will be generally similar to those obtained when the center of gravity is at 24 percent of the mean aerodynamic chord in that the airplane will usually not spin but will trim at flat stalled attitudes.

2. Spins will be obtained only when the ailerons are partially or fully against the spin. Rudder reversal will be ineffective in terminating the spins obtained, but moving the ailerons to full with the spin will terminate the spin rotation. In order to recover from the stalled glides that will be obtained after termination of the spin rotation it will be necessary to reverse the elevator rapidly from full up to 10° down and from full up to 35° down when the center of gravity is at 30 and 35 percent of the mean aerodynamic chord, respectively.

3. The airplane will be capable of tumbling and elevator reversal will be ineffective in terminating the tumble. The accelerations encountered in the tumble may be dangerous to a pilot.

4. To insure against undesirable longitudinal-trim characteristics and to eliminate the tumbling tendencies of the airplane it is necessary to limit the rearward movement of the center of gravity. If the center of gravity is not permitted to move farther rearward than 25 percent of the mean aerodynamic chord the airplane will not tumble and will have satisfactory longitudinal-trim characteristics.

5. If the airplane is flown at a center-of-gravity position rearward of 25 percent of the mean aerodynamic chord, it is recommended that no spins be attempted on this airplane and that care be exercised when maneuvering to avoid stalling the airplane with its nose up near the vertical.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

Walter J. Klinar
Walter J. Klinar
Aeronautical Research Scientist

Ira P. Jones Jr.
Ira P. Jones, Jr.
Aeronautical Research Scientist

Approved: Thomas A. Harris.
Thomas A. Harris
Chief of Stability Research Division

VL

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE CONSOLIDATED VULTEE 7002 AIRPLANE AS SIMULATED ON THE $\frac{1}{20}$-SCALE SPIN MODEL

	Single vertical tail	Dual vertical tail
Length, over-all, ft	41.37	41.37
Wing:		
Span, ft	29.42	22.83
Area, sq ft	375	366.4
Section, parallel to airplane center line	NACA $65_{(06)}$-006.5	NACA $65_{(06)}$-006.5
Mean aerodynamic chord, ft	16.99	16.99
Leading edge $\bar{c}$ behind leading apex angle wing, in.	101.98	101.98
Sweepback of leading edge of wing, deg	60	60
Tip chord, in.	0	68.6
Root chord, in.	305.8	305.8
Wing dihedral, deg	0	0
Taper ratio	0	0.224
Aspect ratio	2.32	1.42
Distance from c.g. to elevon hinge, ft	10.53	10.53
Distance from c.g. to rudder hinge, ft	11.86	11.86
Elevon:		
Chord behind hinge line (constant), in.	34.4	34.4
Area of each elevon behind hinge line, sq ft	33.2	25.73
Vertical tail:		
Total area, sq ft	67.0	50
Rudder area behind hinge line, sq ft	13.4	12.4
Chord behind hinge line (constant), in.	19.2	21.0
Aspect ratio (b^2/S)	1.15	1.0

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TABLE II.- CONDITIONS TESTED ON THE $\frac{1}{20}$-SCALE MODEL OF THE 7002 AIRPLANE

Center-of-gravity position (percent $\bar{c}$)	Vertical-tail installation	Type of launch	Data presented in
Spin tests			
30	Single	Erect spin	Chart 1
35	Single	Erect spin	Chart 2
30	Single and dual	Erect spin	Chart 3
Dynamic elevator-movement tests			
30	Single	Erect spin	Table IV
35	Single	Erect spin	Table IV
Tumbling tests			
30	Single	Tumble	Table V
35	Single	Tumble	Table V

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TABLE III.- COMPARISON OF MASS CHARACTERISTICS AND INERTIA MASS PARAMETERS OF THE LOADINGS TESTED ON THE MODELS AND THE ORIGINAL DESIGN GROSS-WEIGHT LOADING OF THE CONSOLIDATED VULTEE 7002 AIRPLANE

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

No.	Loading	Weight (lb)	Center-of-gravity location		Relative airplane density, μ		Moment of inertia (slug-ft^2)			Mass parameters		
			$x/\bar{c}$	$z/\bar{c}$	At sea level	At 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												
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}
Model values												
2	Center of gravity at 30 percent $\bar{c}$	12,175	.30	-.00125	14.4	22.9	4,013	28,539	30,350	-749	-55	804
3	Center of gravity at 35 percent $\bar{c}$	12,175	.35	.0088	14.4	22.9	4,002	26,826	28,620	-697	-55	752

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TABLE IV.- EFFECT OF DYNAMIC ELEVATOR MOVEMENT ON THE LONGITUDINAL-TRIM CHARACTERISTICS OF THE MODEL

[Landing gear retracted; cockpit closed; rudder full with the spin; ailerons neutral; elevator reversed after forced spin rotation damped out]

Initial elevator setting (deg)	Final elevator setting (deg)	Behavior of model following elevator movement
Center of gravity at 30 percent $\bar{c}$		
20 up	5 down	Model remains in flat stalled glide
20 up	10 down	Model pitched downward and entered a dive
20 up	15 down	Model pitched downward and went inverted
20 up	20 down	Model pitched downward and went inverted
Center of gravity at 35 percent $\bar{c}$		
20 up	20 down	Model oscillates somewhat in pitch but remains in stalled attitude
20 up	35 down	Model makes several pitching oscillations and then pitches inverted. Sometimes rolls about X-axis as it pitches out of stalled glide
20 up	50 down	Model pitches inverted after a few pitching oscillations

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TABLE V.- TUMBLING CHARACTERISTICS OF MODEL

[Full-scale horizontal velocity component during tumble is approximately 50 ft/sec; ailerons and rudder neutral]

Center-of-gravity position (percent $\bar{c}$)	Method of launching	Elevator position	Approximate rate of descent, full scale (ft/sec)	[a]Behavior of model
30	Released from vertical nose up attitude	20° Up	218	1. Enters motion that is a combination of tumbling, rolling, and yawing. 2. Oscillates in pitch about a lateral axis and damps.
		0°	221	[b]1. Tumbles with positive pitching rotation. 2. Enters a motion that is a combination of tumbling, rolling, and yawing. 3. Oscillates in pitch about lateral axis and damps.
		20° down	221	1. Tumbles with positive pitching rotation. 2. Tumbles with negative pitching rotation. 3. Enters motion that is a combination of tumbling, rolling, and yawing. 4. Rolls so that elevator opposes tumble and damps.
30	With positive pitching rotation	20° up	231	1. Tumbles. 2. Enters motion that is a combination of tumbling, rolling, and yawing. 3. Pitching damps and model goes into a roll.
		20° down	240	1. Enters motion that is a combination of tumbling, rolling, and yawing. 2. Pitching damps and model goes into a roll.
30	With negative pitching rotation	20° up	235	1. Enters motion that is a combination of tumbling, rolling, and yawing. 2. Stops tumbling in negative direction and tumbles with positive pitching rotation.
		20° down	235	1. Tumbles. 2. Enters motion that is a combination of tumbling, rolling, and yawing.
35	Released from vertical nose up attitude	20° up	218	1. Tumbles with positive pitching rotation. 2. Enters motion that is a combination of tumbling, rolling, and yawing. 3. Oscillates in pitch about lateral axis and damps.
		0°	225	1. Tumbles with positive pitching rotation. 2. Enters motion that is a combination of tumbling, rolling, and yawing. 3. Oscillates in pitch about lateral axis and damps.
		20° down	221	1. Tumbles with negative pitching rotation. 2. Enters motion that is a combination of tumbling, rolling, and yawing.
35	With positive pitching rotation	20° up	234	1. Tumbles; sometimes tumble has a rolling oscillation. 2. Enters motion that is a combination of tumbling, rolling, and yawing.
		20° down	234	1. Tumbles; sometimes tumble has a rolling oscillation. 2. Forced pitching rotation damps.
35	With negative pitching rotation	20° up	218	1. Forced pitching rotation damps and model tumbles with positive pitching rotation. 2. Forced pitching rotation damps and model goes into a roll.
		0°	229	Tumbles; sometimes tumble has a rolling oscillation.
		20° down	221	1. Tumbles and begins to roll (as it tumbles) before striking safety net. 2. Tumble damps.

[a] Each numbered comment indicates the observed behavior of the model for a given launching. The numbers do not indicate a series of successive events during a given launching.

[b] Motion defined as merely a tumble consists of a pitching motion about the Y-axis.

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TABLE VI.- INSTANTANEOUS NORMAL AND TRANSVERSE ACCELERATIONS AT PILOTS HEAD DURING TUMBLES

[Center of gravity at 35 percent $\bar{c}$, full-scale values given]

Time (sec)	Elevator down			Elevator up			Time (sec)	Elevator down		
	α (deg)	[a]Accelerations		α (deg)	[a]Accelerations			α (deg)	[a]Accelerations	
		[b]Normal (g)	[c]Transverse (g)		[b]Normal (g)	[c]Transverse (g)			[b]Normal (g)	[c]Transverse (g)
0	-178	1.55	3.70	-179	2.03	2.04	0	0	-1.74	4.90
.064	172	1.39	4.34	-171	1.92	2.40	.067	-16	-1.87	5.16
.127	159	1.13	5.39	-163	1.60	2.73	.134	-27	-2.08	5.38
.191	147	.42	6.19	-154	1.10	3.81	.207	-42	-2.29	5.77
.255	132	-.09	6.97	-143	.63	4.63	.268	-57	-2.55	6.22
.318	117	-.46	7.58	-131	.24	4.86	.335	-73	-1.69	6.98
.382	101	-.80	8.32	-119	1.08	5.78	.402	-90	-.36	6.53
.446	85	-1.63	8.64	-105	2.31	8.25	.469	-105	-.27	5.82
.510	69	-2.08	8.53	-87	-2.37	9.74	.536	-120	.18	5.37
.573	52	↓	↓	-69	-3.20	8.80	.603	-132	.80	4.73
.637	34			-52	-3.36	8.31	.670	-145	1.47	4.07
.701	19			-34	-3.29	7.55	.737	-154	2.07	3.27
.764	1			-20	-3.22	6.50	.804	-164	1.20	2.18
.828	-13			-4	-3.39	6.00	.871	-170	.03	1.67
.892	-32			9	-3.12	4.77	.938	-179	-.67	1.45
.956	-49			20	-1.12	4.58	1.005	174	-1.20	1.52
1.019	-67	-2.45	8.44	34	.81	5.73	1.072	166	-1.38	1.71
1.083	-83	-3.34	7.70	48	.32	6.31	1.139	158	-1.81	1.92
1.147	-99	-4.55	6.26	62	-.38	7.44	1.206	148	-2.51	2.36
1.210	-113	-3.11	5.25	79	-1.08	8.09	1.273	137	-4.83	2.88
1.274	-127	-1.94	4.92	95	-1.60	7.96	1.340	124	-8.60	5.13
1.338	-140	-1.66	4.83	110	-2.06	7.85	1.407	108	-9.64	9.38
1.401	-154	-1.71	4.56	128	-3.55	7.65	1.474	84	-4.05	16.69
1.465	-165	-1.65	4.33	143	-4.89	5.27	1.541	59	5.13	12.65
1.529	-176	-1.42	4.19	157	-3.84	3.80	1.608	42	2.68	7.56
1.592	----	-----	----	168	-2.81	2.92	1.675	28	1.08	5.60
1.656	----	-----	----	178	-2.02	2.68	1.742	18	2.35	4.51
1.720	----	-----	----	-172	-1.38	2.63	1.809	7	2.95	3.39
1.784	----	-----	----	-162	-.59	2.43	1.876	-2	3.47	2.36
1.847	----	-----	----	----	-----	----	1.943	-9	3.90	1.56

[a] Component of acceleration due to gravity not included.

[b] Component of acceleration directed through long axis of pilot.

[c] Component of acceleration normal to long axis of pilot.

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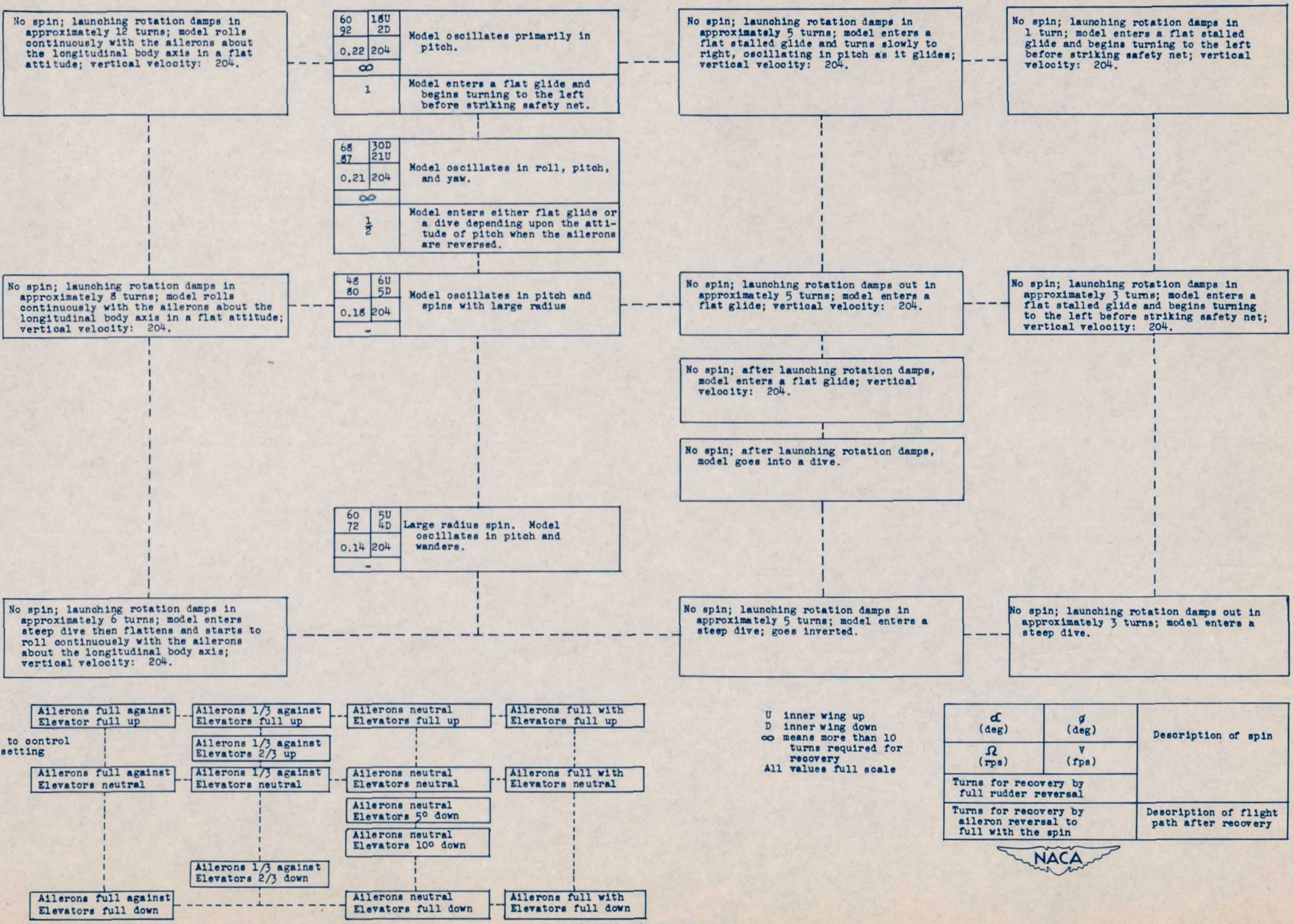
CHART 1.- SPIN CHARACTERISTICS OF MODEL WITH CENTER OF GRAVITY AT 30 PERCENT $\bar{c}$ AND SINGLE VERTICAL TAIL INSTALLED

[Landing gear retracted; cockpit closed; model launched in an erect attitude with the rudder full with the direction of rotation; rotation to pilot's right]



No spin; launching rotation damps in approximately 12 turns; model rolls continuously with the ailerons about the longitudinal body axis in a flat attitude; vertical velocity: 204.

60 92	18U 2D	Model oscillates primarily in pitch.
0.22	204	
∞		
1		Model enters a flat glide and begins turning to the left before striking safety net.

No spin; launching rotation damps in approximately 5 turns; model enters a flat stalled glide and turns slowly to right, oscillating in pitch as it glides; vertical velocity: 204.

No spin; launching rotation damps in 1 turn; model enters a flat stalled glide and begins turning to the left before striking safety net; vertical velocity: 204.

68 87	30D 21U	Model oscillates in roll, pitch, and yaw.
0.21	204	
∞		
$\frac{1}{2}$		Model enters either flat glide or a dive depending upon the attitude of pitch when the ailerons are reversed.

No spin; launching rotation damps in approximately 8 turns; model rolls continuously with the ailerons about the longitudinal body axis in a flat attitude; vertical velocity: 204.

48 80	6U 5D	Model oscillates in pitch and spins with large radius
0.18	204	
-		

No spin; launching rotation damps out in approximately 5 turns; model enters a flat glide; vertical velocity: 204.

No spin; launching rotation damps in approximately 3 turns; model enters a flat stalled glide and begins turning to the left before striking safety net; vertical velocity: 204.

No spin; after launching rotation damps, model enters a flat glide; vertical velocity: 204.

No spin; after launching rotation damps, model goes into a dive.

60 72	5U 4D	Large radius spin. Model oscillates in pitch and wanders.
0.14	204	
-		

No spin; launching rotation damps in approximately 6 turns; model enters steep dive then flattens and starts to roll continuously with the ailerons about the longitudinal body axis; vertical velocity: 204.

No spin; launching rotation damps in approximately 5 turns; model enters a steep dive; goes inverted.

No spin; launching rotation damps out in approximately 3 turns; model enters a steep dive.

Key to control setting

Ailerons full against Elevator full up

Ailerons 1/3 against Elevators full up

Ailerons neutral Elevators full up

Ailerons full with Elevators full up

Ailerons 1/3 against Elevators 2/3 up

Ailerons full against Elevators neutral

Ailerons 1/3 against Elevators neutral

Ailerons neutral Elevators neutral

Ailerons full with Elevators neutral

Ailerons neutral Elevators 5° down

Ailerons neutral Elevators 10° down

Ailerons 1/3 against Elevators 2/3 down

Ailerons full against Elevators full down

Ailerons neutral Elevators full down

Ailerons full with Elevators full down

U inner wing up
D inner wing down
∞ means more than 10 turns required for recovery
All values full scale

α (deg)	φ (deg)	Description of spin
Ω (rps)	V (fps)	
Turns for recovery by full rudder reversal		
Turns for recovery by aileron reversal to full with the spin		Description of flight path after recovery

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CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF MODEL WITH CENTER OF GRAVITY AT 35 PERCENT $\bar{c}$ AND SINGLE VERTICAL TAIL INSTALLED

[Landing gear retracted; cockpit closed; model launched in an erect attitude with the rudder full with the direction of rotation; rotation to pilot's right]

80 97	35U 24D
0.34	197
∞	

Model spins in very flat attitude and oscillates greatly in roll. Slight pitching oscillations also present.

No spin; launching rotation damps in approximately 6 turns; model enters a flat stalled glide of large radius; model oscillates in pitch during the glide; vertical velocity: 192.

No spin; launching rotation damps in approximately 4 turns; model enters a flat glide and begins turning to the left before striking safety net; vertical velocity: 197.

44 120	11U 13D
0.11	201
7, ∞	

Model oscillates greatly in pitch and wanders.

80 87	6U 6D
0.27	195
∞	

Flat steady spin with only slight oscillations in roll and pitch.

No spin; launching rotation damps in approximately 5 turns; model enters a wide radius flat glide; model oscillates in pitch during the glide; vertical velocity: 192.

No spin; launching rotation damps in approximately 4 turns; model enters a flat glide which oscillates in pitch and begins turning to the left before striking the safety net; vertical velocity: 197.

No spin; launching rotation damps in approximately 10 turns; model pitches and rolls into a steep dive with continuous rolling with the ailerons about the longitudinal body axis; vertical velocity: 197.

No spin; launching rotation damps in approximately 14 turns; model enters a flat glide, model oscillates in pitch during the glide; vertical velocity: 197.

No spin; launching rotation damps in approximately 5 turns; model enters a flat glide which oscillates in pitch and begins turning to the left before striking the safety net; vertical velocity: 192.

No spin; after launching rotation damps, model enters a flat glide; model oscillates in pitch during the glide; vertical velocity: 197.

No spin; after launching rotation damps, model either pitches inverted or begins a tumble.

Key to control settings

Ailerons full against Elevator full up	Ailerons neutral Elevators full up	Ailerons full with Elevator full up
	Ailerons 1/3 against Elevators 2/3 up	
Ailerons full against Elevators neutral	Ailerons neutral Elevators neutral	Ailerons full with Elevators neutral
Ailerons full against Elevators full down	Ailerons neutral Elevators full down	Ailerons full with Elevators full down
	Ailerons neutral Elevators 50° down	
	Ailerons neutral Elevators 60° down	

U inner wing up
D inner wing down
∞ means more than 10 turns required for recovery
All values full scale

α (deg)	ϕ (deg)	Description of spin
Ω (rps)	V (fps)	
Turns for recovery by full rudder reversal		

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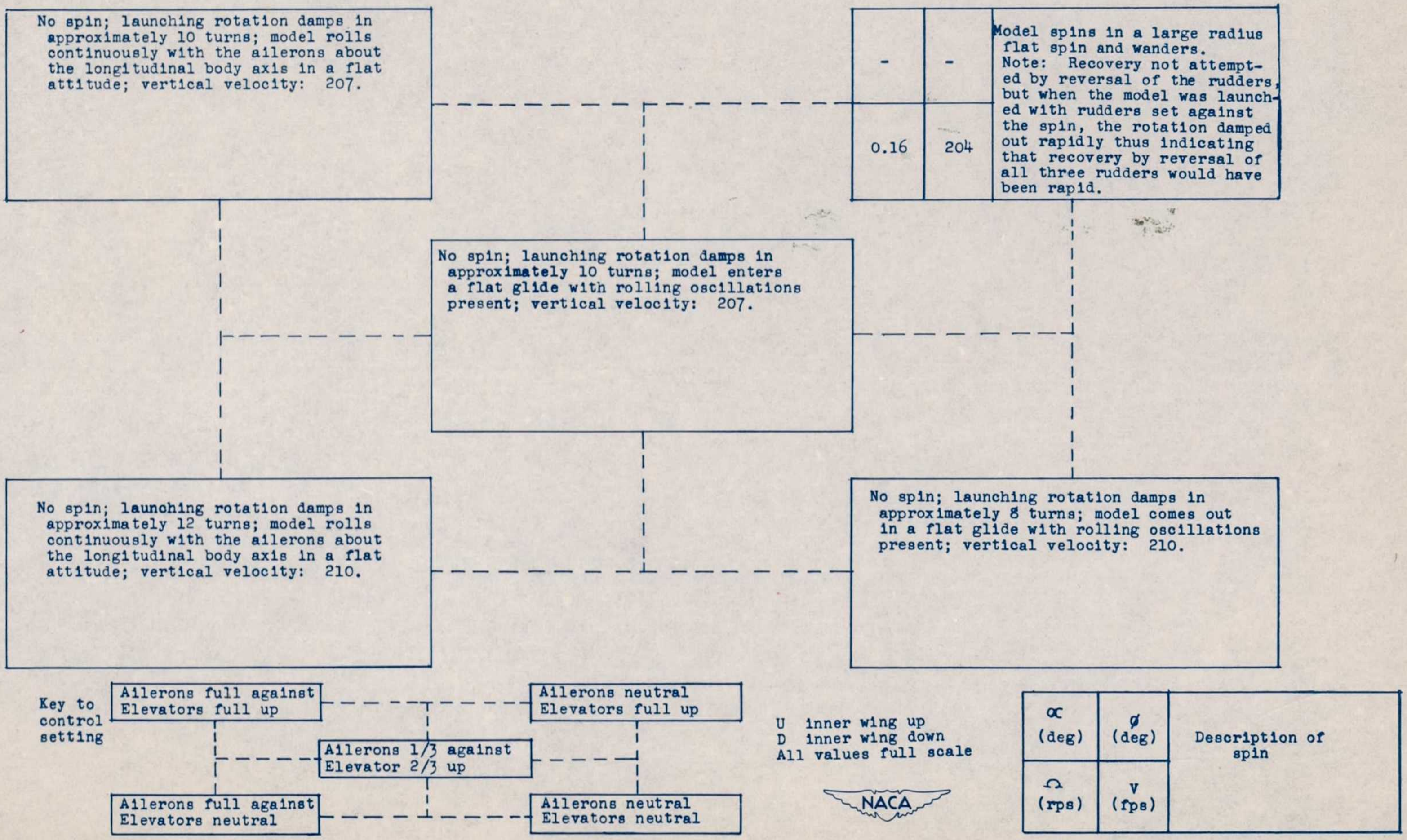
CHART 3.- SPIN CHARACTERISTICS OF MODEL WITH CENTER OF GRAVITY AT 30 PERCENT $\bar{c}$ WITH SINGLE AND DUAL VERTICAL TAILS INSTALLED

[Landing gear retracted; cockpit closed; model launched in an erect attitude with the rudder fixed full with the direction of rotation unless otherwise noted; rotation to pilot's right]



No spin; launching rotation damps in approximately 10 turns; model rolls continuously with the ailerons about the longitudinal body axis in a flat attitude; vertical velocity: 207.

-	-	Model spins in a large radius flat spin and wanders. Note: Recovery not attempted by reversal of the rudders, but when the model was launched with rudders set against the spin, the rotation damped out rapidly thus indicating that recovery by reversal of all three rudders would have been rapid.
0.16	204	

No spin; launching rotation damps in approximately 10 turns; model enters a flat glide with rolling oscillations present; vertical velocity: 207.

No spin; launching rotation damps in approximately 12 turns; model rolls continuously with the ailerons about the longitudinal body axis in a flat attitude; vertical velocity: 210.

No spin; launching rotation damps in approximately 8 turns; model comes out in a flat glide with rolling oscillations present; vertical velocity: 210.

Key to control setting

U inner wing up
D inner wing down
All values full scale

α (deg)	ϕ (deg)	Description of spin
Ω (rps)	V (fps)	

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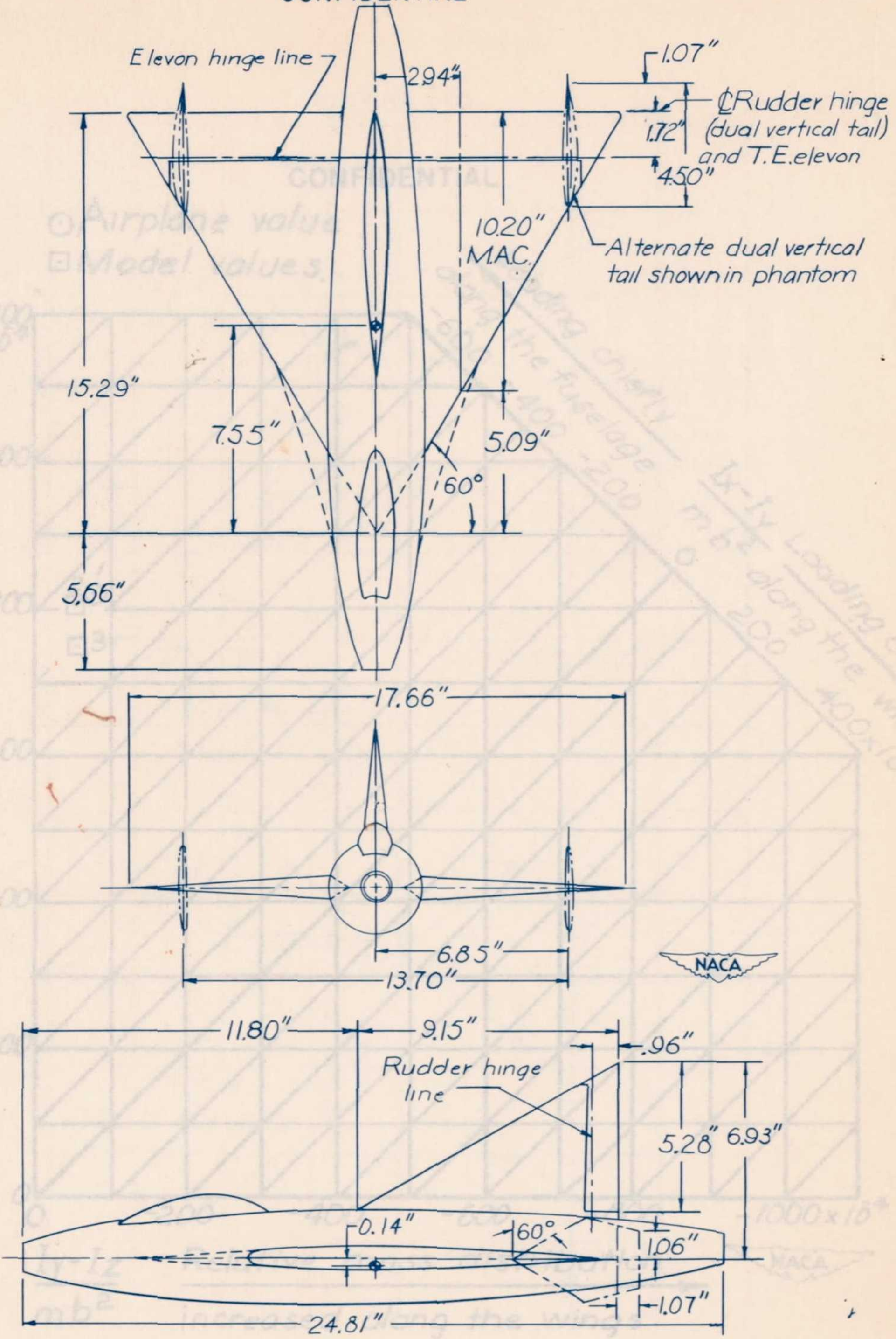

Figure 1.- Drawing of a $\frac{1}{20}$-scale model of the Consolidated Vultee 7002 airplane as tested in the free-spinning tunnel. Center of gravity is shown at 24.1 percent $\bar{c}$.

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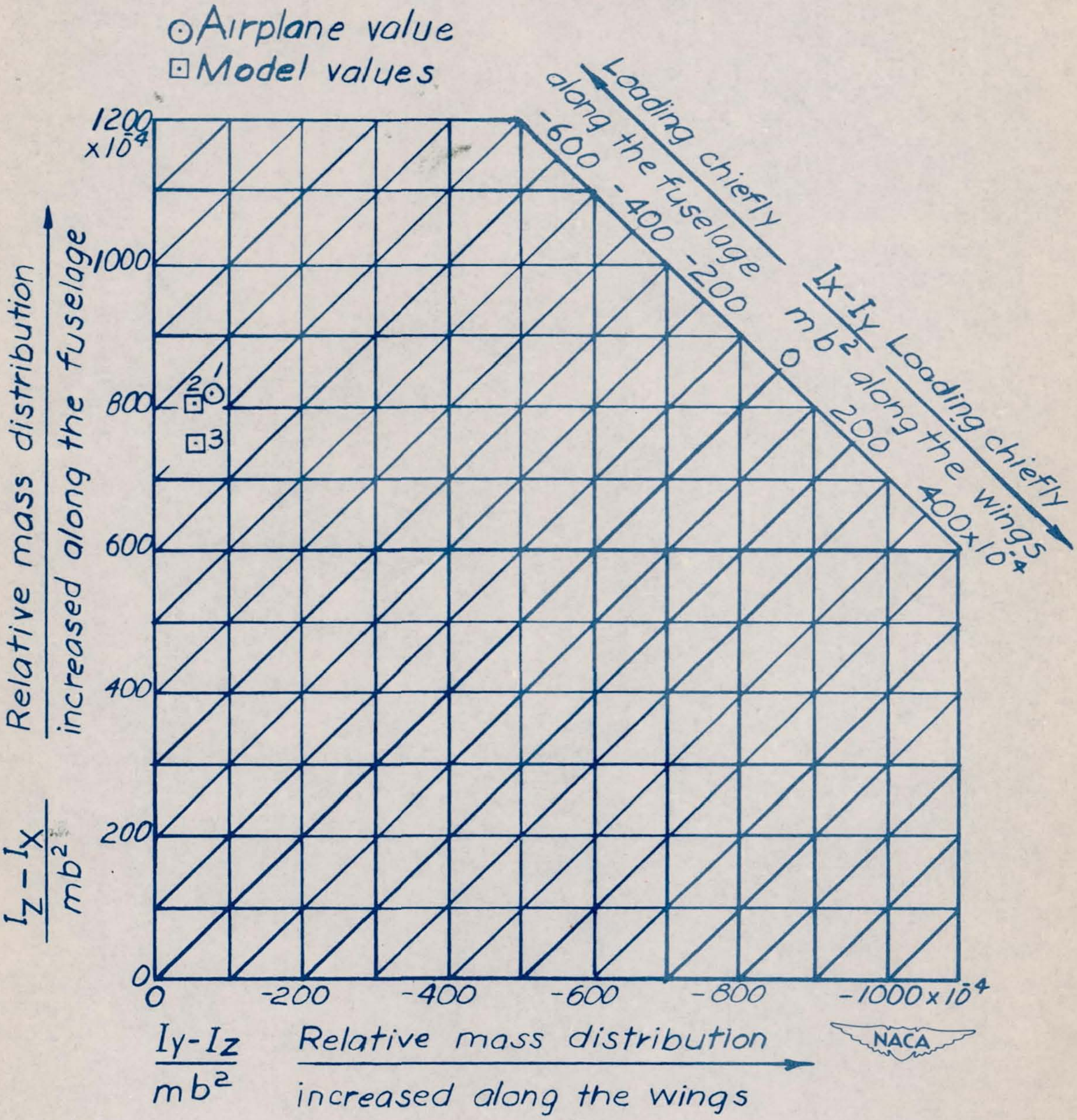

Figure 2.– Comparison of the inertia mass parameters for the design gross weight of the 7002 airplane and the loadings tested on the model.

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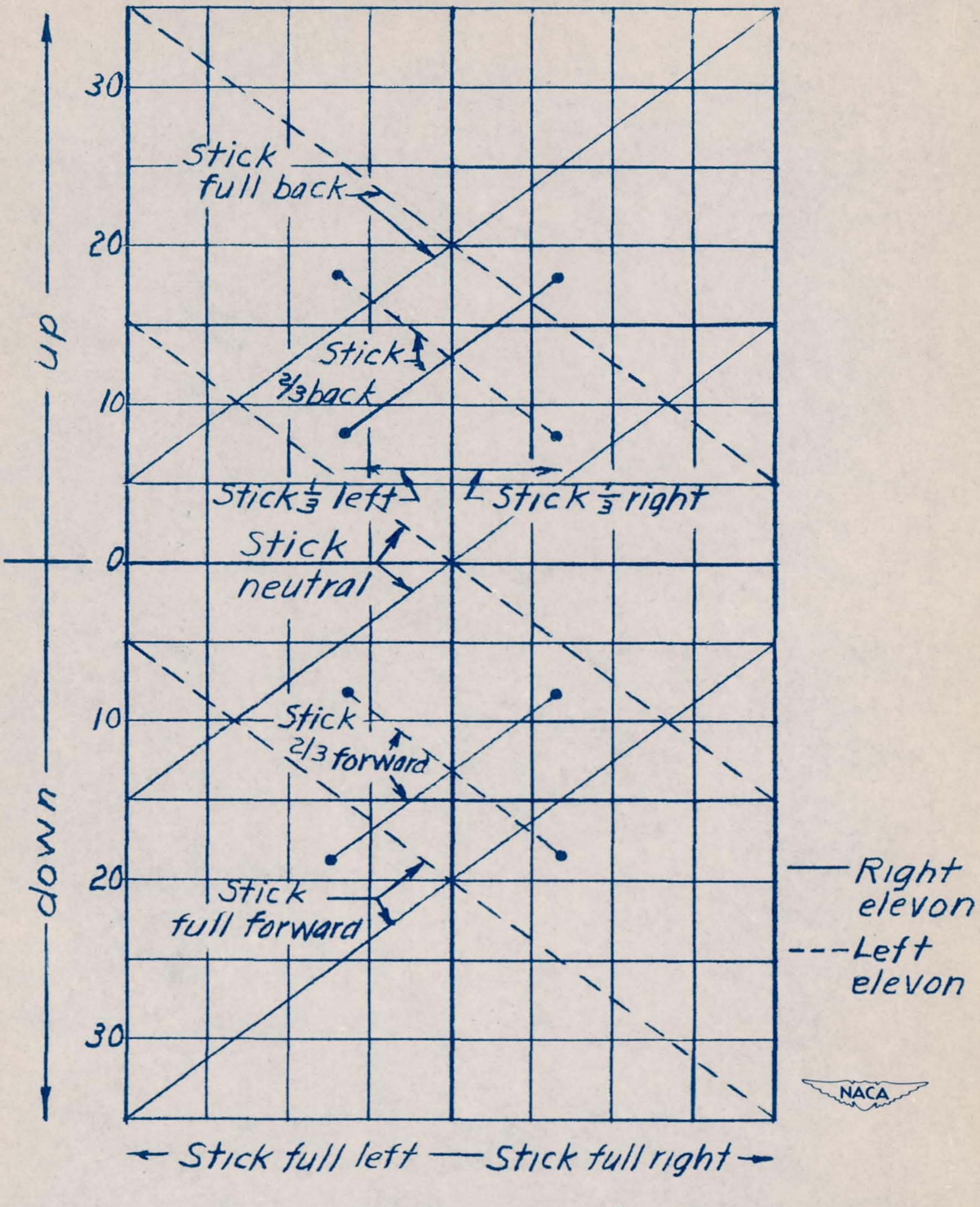

Figure 3.– Elevon deflections used on the $\frac{1}{20}$– scale model of the 7002 airplane for various control–stick positions for the single– or dual–vertical–tail configurations.

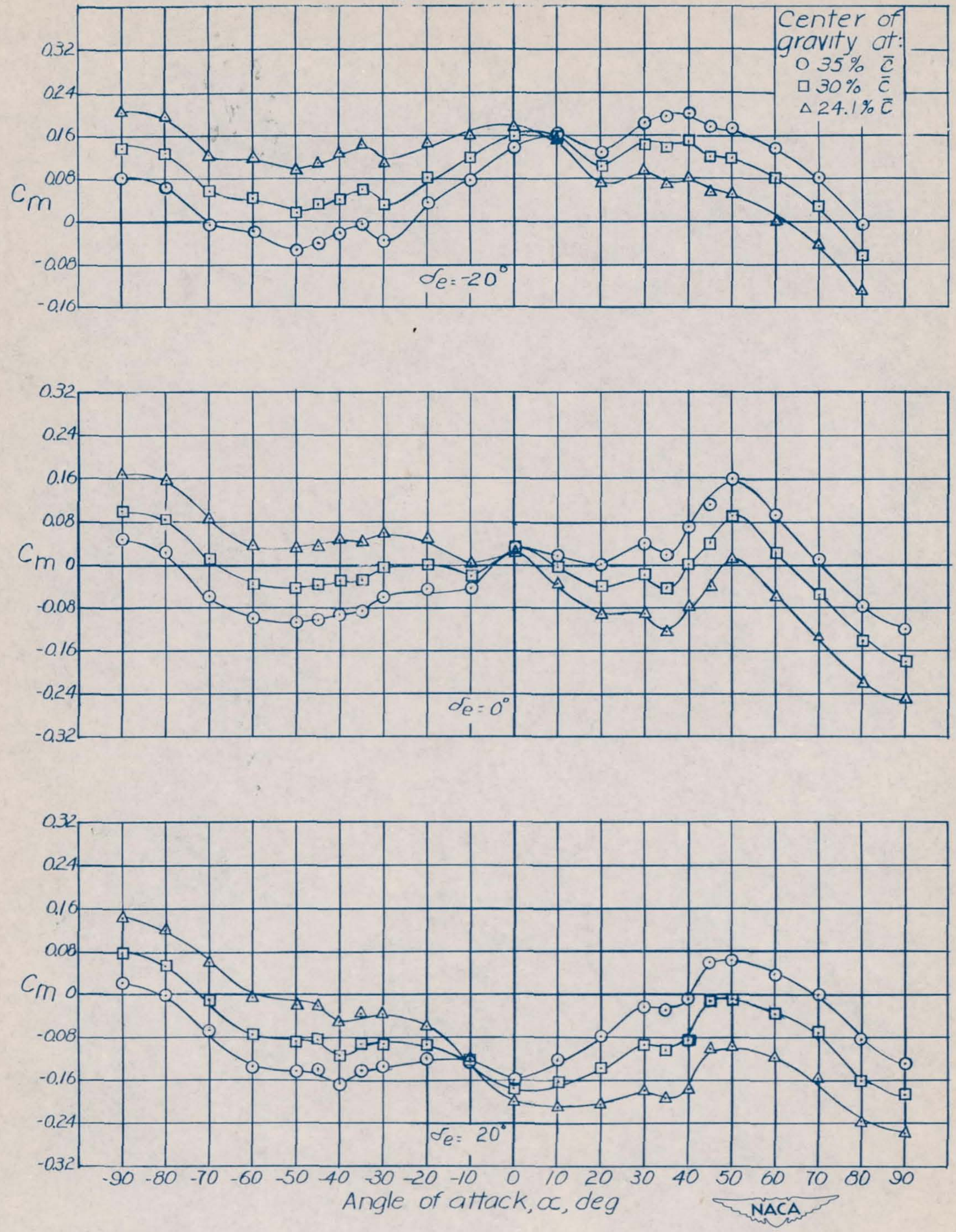

Figure 4.- Pitching-moment characteristics of the $\frac{1}{20}$-scale model of the Consolidated Vultee 7002 airplane (wing fillets removed) with single vertical tail. $\psi = 0°$; $\delta_r = 0°$; $\delta_a = 0°$.

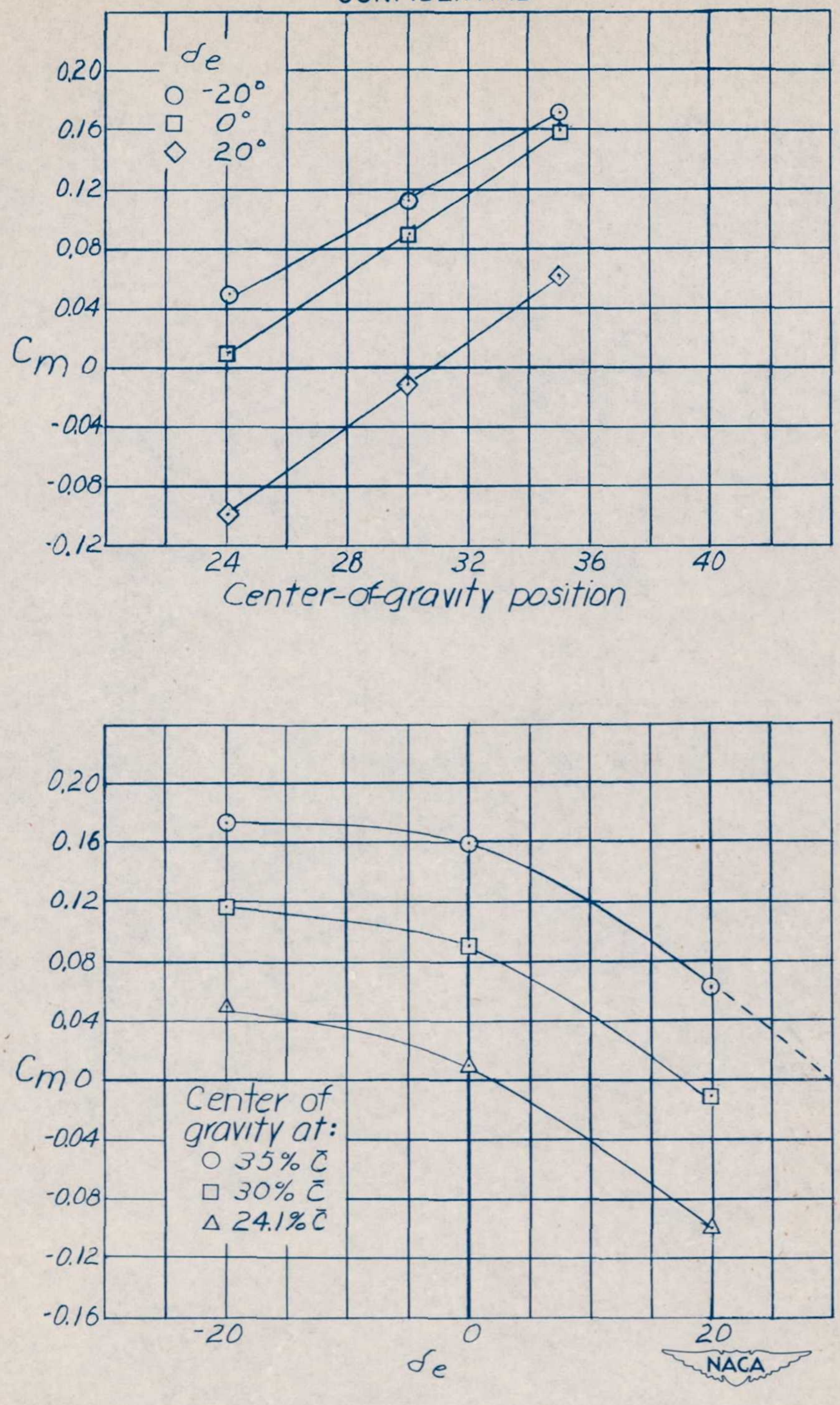

Figure 5.– Variation of pitching-moment coefficient with center-of-gravity position and elevator setting for the $\frac{1}{20}$- scale model of the Consolidated Vultee 7002 airplane (wing fillets removed) with single vertical tail. $\alpha = 50^{\circ}$; $\psi = 0^{\circ}$; $\delta_r = 0^{\circ}$; $\delta_a = 0^{\circ}$.

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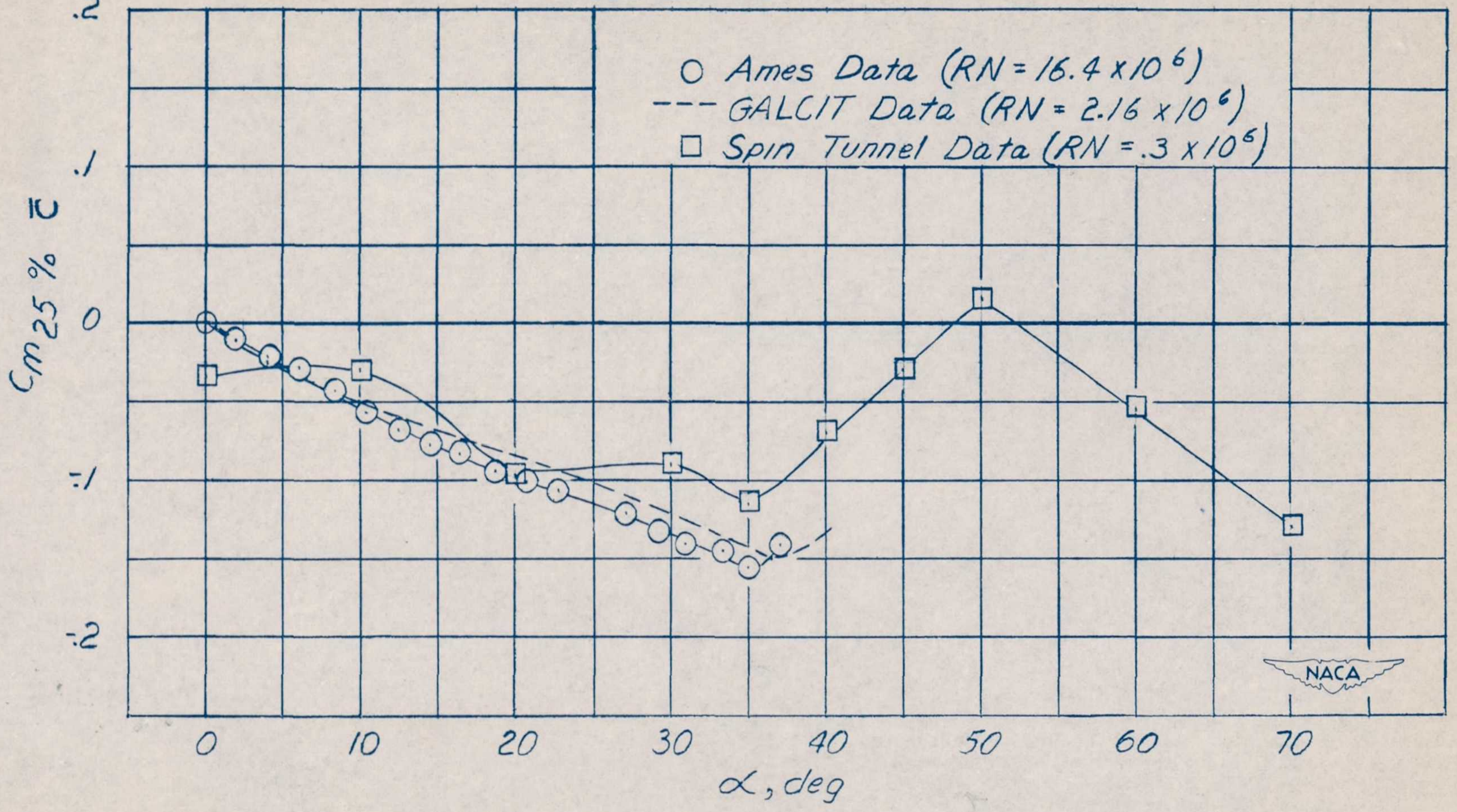

Figure 6.- Comparison of the 7002 pitching-moment data from the Langley spin tunnel, Galcit, and the Ames full-scale tunnel.

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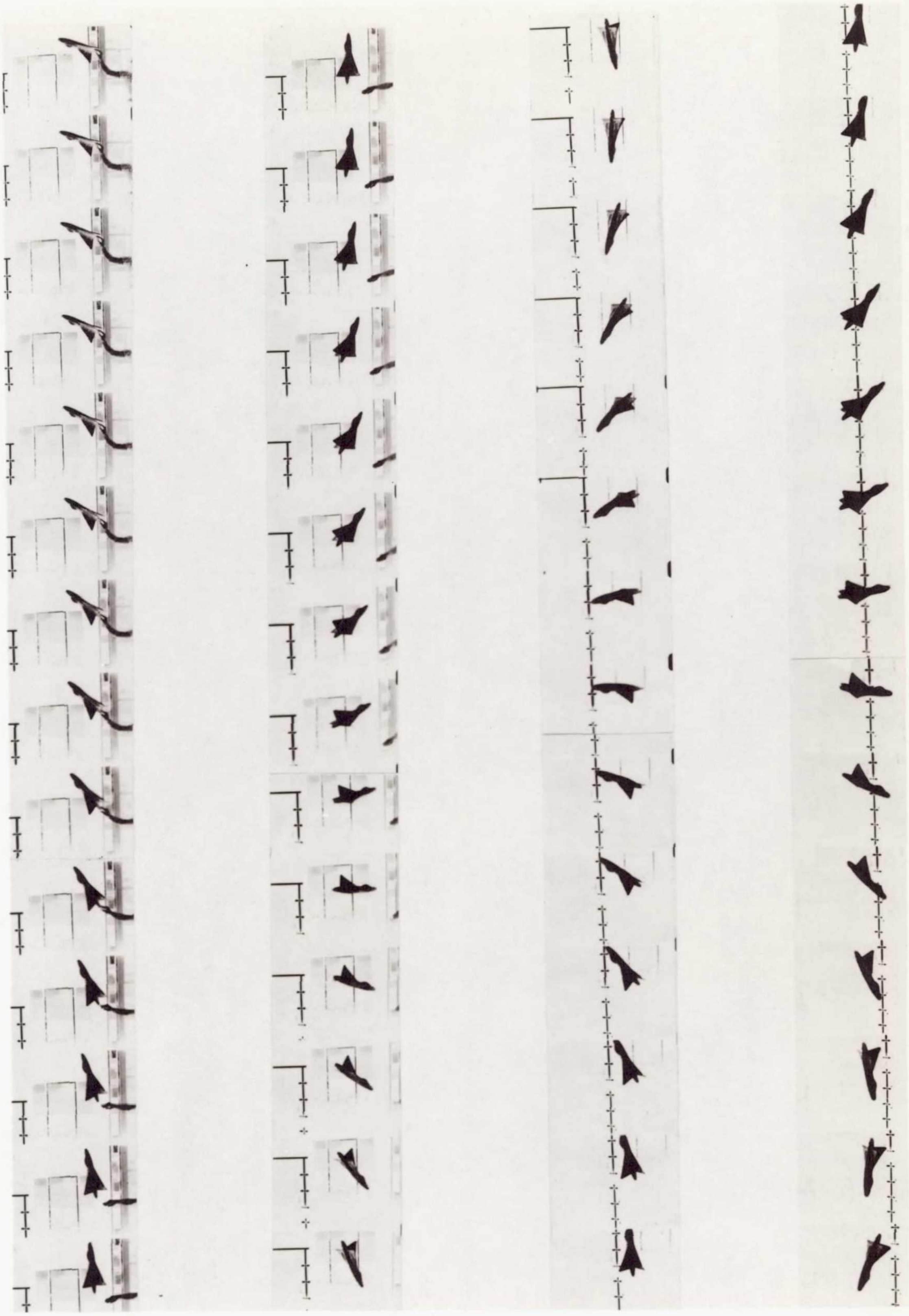


Figure 7.– Typical motion of model during a tumble consisting only of pitching about the Y-axis. Pictures taken at approximately 64 frames per second.

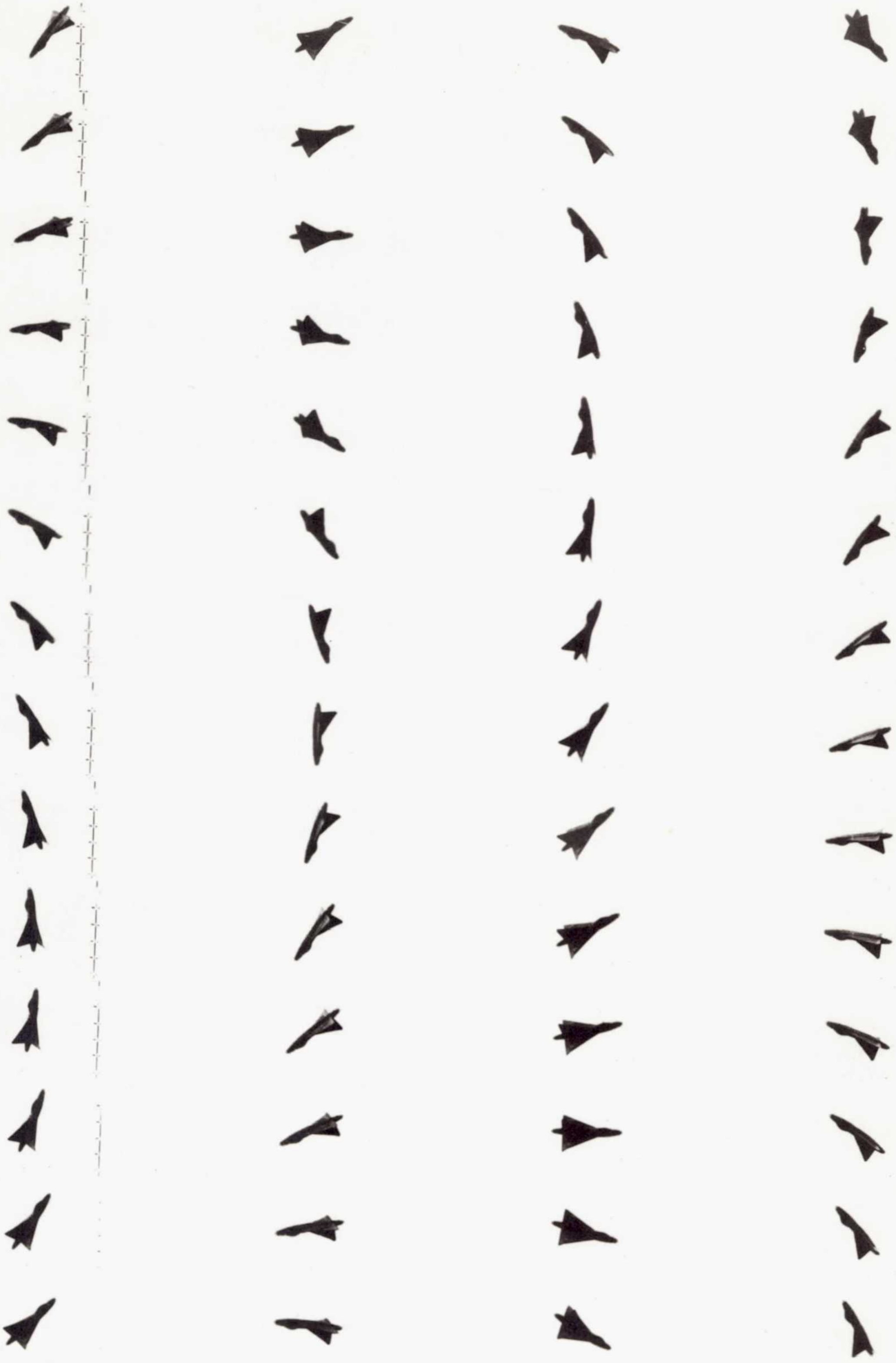
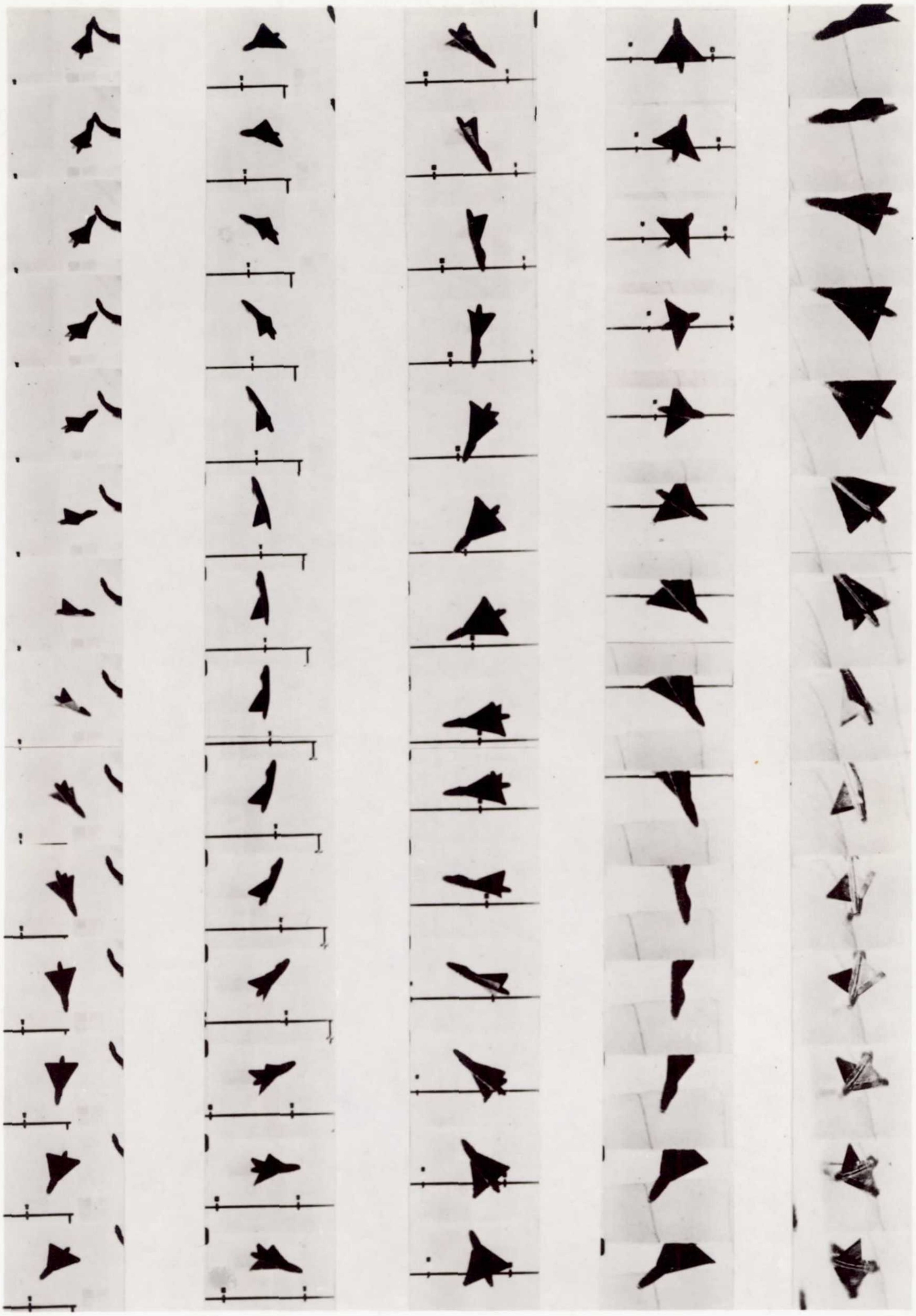
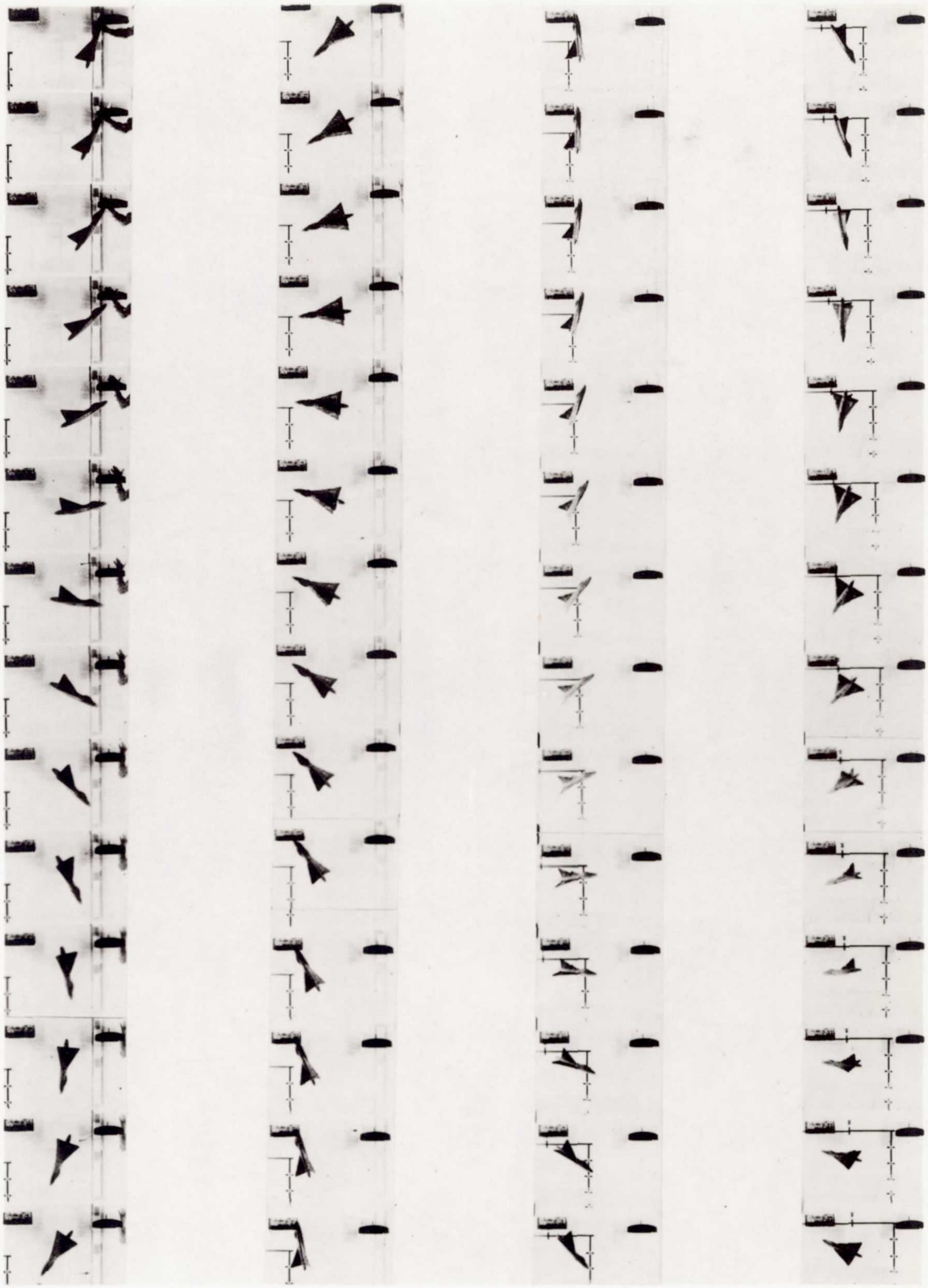


Figure 7.- Concluded.



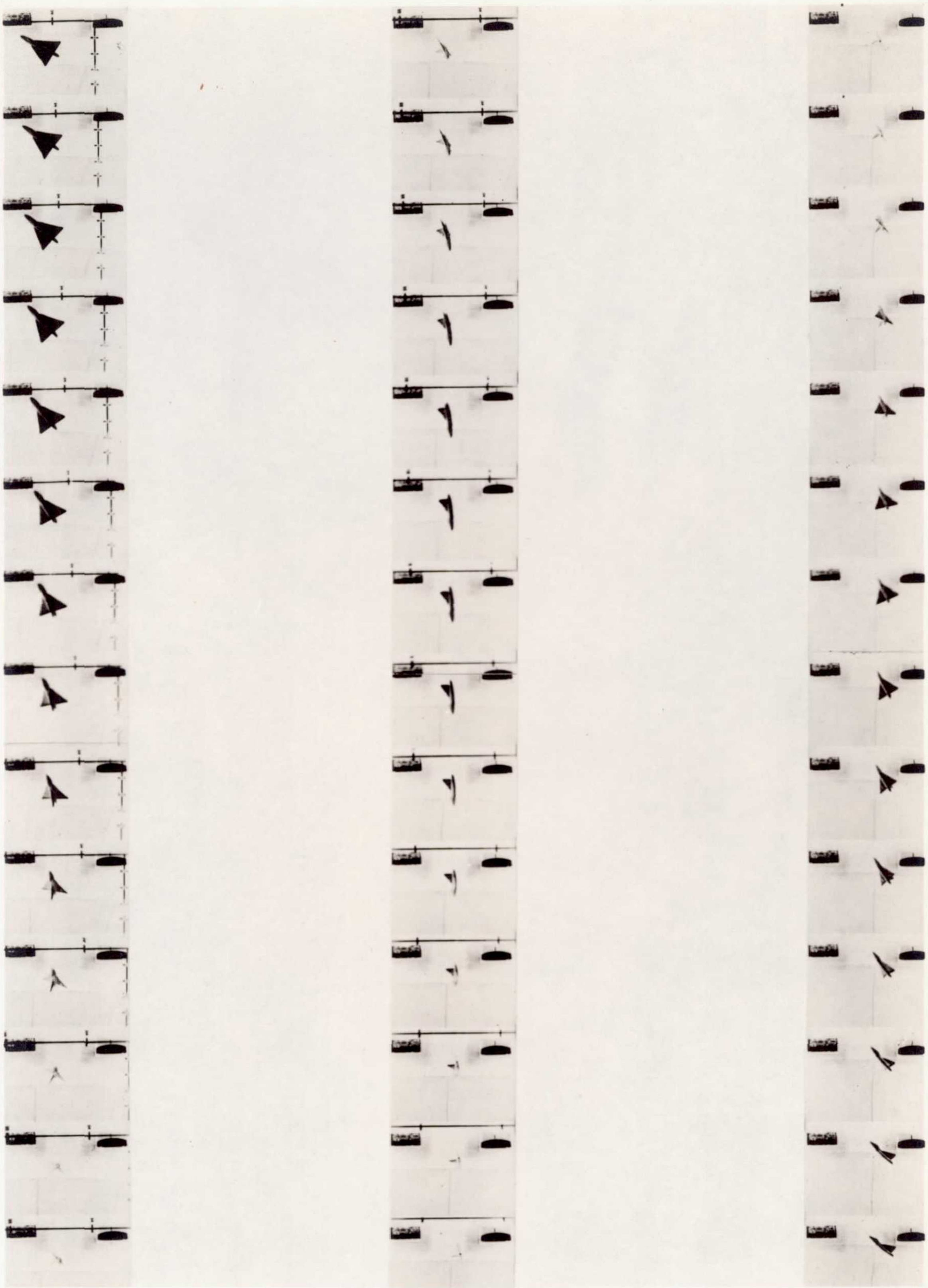
(a) Motion consisting of both pitching and rolling.

Figure 8.– Sequence pictures showing tumbling motion of model. Pictures taken at approximately 64 frames per second.



(b) Motion consisting of pitching, rolling, and yawing.

Figure 8.– Continued.



(b) Concluded.

Figure 8.– Concluded.

[redacted]

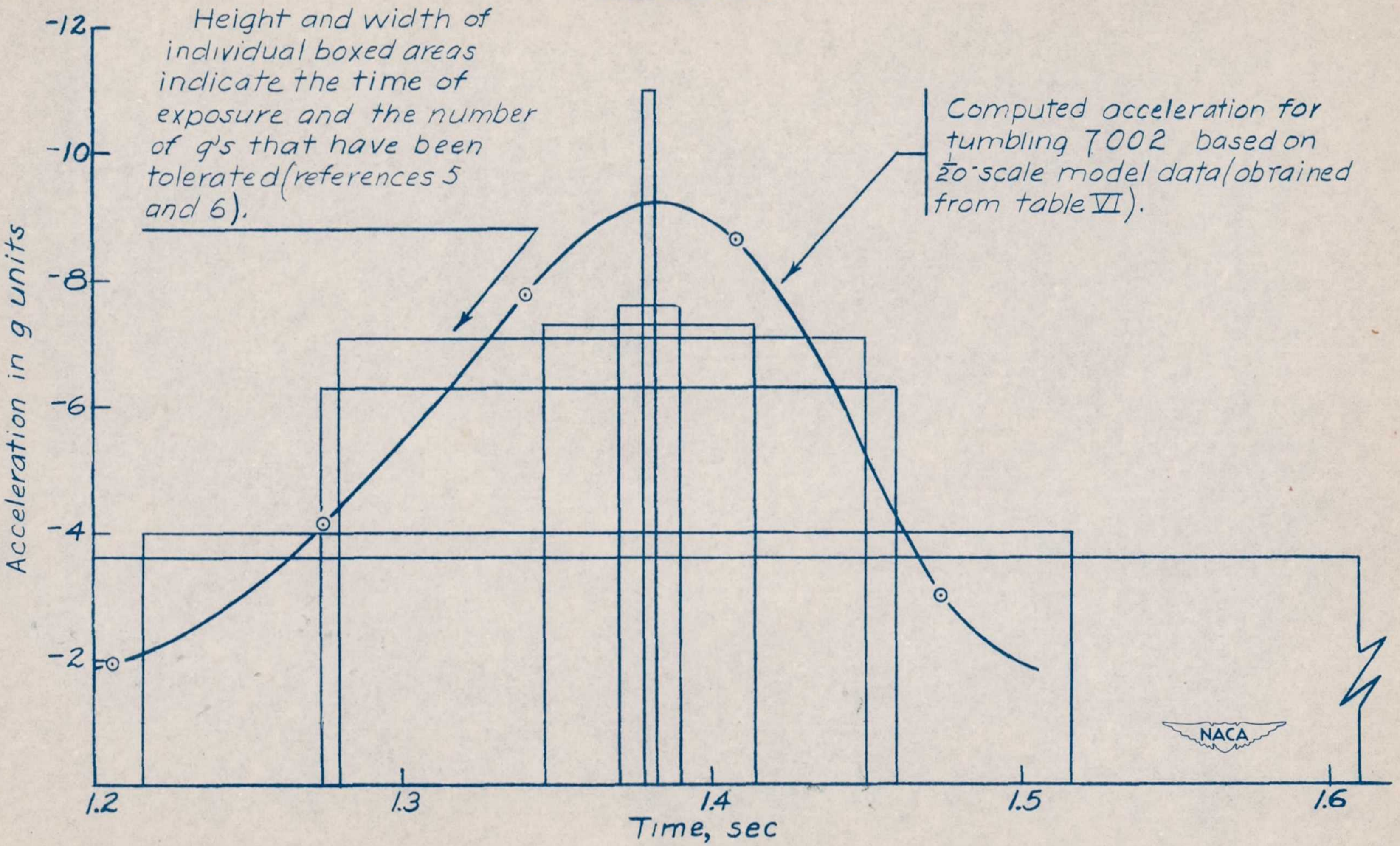


Figure 9.– Comparison between negative g tolerated in tests and the computed acceleration likely to exist at a pilot's head during a portion of a tumble of the 7002 airplane (based on the $\frac{1}{20}$ – scale model results).

[redacted]