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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-88 AIRPLANE WITH A VEE TAIL

By

Theodore Berman

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

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FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-88 AIRPLANE WITH A VEE TAIL

By Theodore Berman

SUMMARY

An investigation of the spin and recovery characteristics of a $\frac{1}{24}$-scale model of the McDonnell XP-88 airplane has been conducted in the Langley 20-foot free-spinning tunnel. Results of tests with a conventional tail have been previously reported; the results presented herein are for the model with a vee tail installed. The effects of control settings and movements on the erect and inverted spin and recovery characteristics of the model in the normal loading were determined. Tests of the model in the long-range loading also were made. The investigation included leading-edge-flap, spin-recovery-parachute, and rudder-pedal-force tests.

The recovery characteristics of the model were satisfactory for the normal loading. Deflecting the leading-edge flaps improved recoveries. The results indicated that with the external wing tanks installed (long-range loading) recoveries may be poor and, therefore, if a spin is inadvertently entered in this condition the tanks should be jettisoned if recovery does not appear imminent immediately after it is attempted. A 10-foot spin-recovery tail parachute with a towline 40 feet long and a drag coefficient of 0.63 was found to be effective for spin recovery. The rudder pedal force required for spin recovery was indicated to be within the capabilities of the pilot.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, an investigation of the spin and recovery characteristics of the McDonnell XP-88 airplane with a conventional tail and an alternate vee tail has been conducted with a $\frac{1}{24}$-scale model in the Langley 20-foot free-spinning tunnel. The results of tests of the model with the conventional tail were presented in reference 1. The results of tests of the same model with a vee tail installed are reported herein. The McDonnell XP-88 airplane is a midwing, jet-propelled fighter with a sweptback wing and sweptback tail surfaces.

The erect and inverted spin and recovery characteristics of the model were determined for the clean condition, normal loading. The effects of changes in loading, changes in control deflections, and deflection of the wing leading-edge flaps were also investigated. The test program was concluded with tests to determine the minimum tail parachute size necessary to effect satisfactory spin recovery in an emergency and tests to determine the force necessary to move the rudder pedals for recovery from a spin.

SYMBOLS

b	wing span, feet
S	wing area, square feet
c	wing or elevator chord at any station along the span
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and water line 26.2 to mean aerodynamic chord (positive when center of gravity is below 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, slug per cubic foot
μ	relative density of airplane $\left(\frac{m}{\rho Sb}\right)$
α	angle between water line 26.2 and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, revolutions per second
σ	helix angle, angle between flight path and vertical, degrees (For the tests of this model, the average absolute value of the helix angle was approximately 4°.)
β	approximate angle of sideslip at center of gravity, degrees (Sideslip is inward when inner wing is down by an amount greater than the helix angle.)

APPARATUS AND METHODS

Model

The $\frac{1}{24}$-scale model of the McDonnell XP-88 airplane was built and prepared for testing by the Langley Laboratory. The vee tail was installed on the model after completion of tests with the conventional tail. A three-view drawing of the model as tested in the clean condition is shown in figure 1. A photograph of the model is shown as figure 2. Figure 3 shows the installation of the wing-tip fuel tanks for the long-range loading. The dimensional characteristics of the airplane are given in table I. With the vee tail installed on the model, the other variables such as weight, center of gravity, and moment of inertia were the same as those for the model with the conventional tail.

The model was ballasted with lead weights to obtain dynamic similarity to the airplane at an altitude of 15,000 feet ($\rho = 0.001496$ slug per cubic foot). A remote-control mechanism was installed in the model to actuate the controls or open the parachute for recovery tests. Sufficient moments were exerted on the control surfaces to reverse the controls fully and rapidly.

The trailing edge of the vee tail was equipped with movable control surfaces designated "ruddervators." These surfaces were moved together to provide longitudinal control and differentially for directional control. In the normal manner, then, longitudinal movements of the stick provided longitudinal control and movement of the rudder pedals provided directional control. For convenience in this report, longitudinal movement of the stick will be referred to as elevator deflection and rudder pedal movement will be referred to as rudder deflection. The equivalent of full elevator deflection and full rudder deflection could be obtained simultaneously with no restrictions being placed on movement of the ruddervators.

Tail-damping power factor, as given in table I, was computed from the formula given in reference 2 by arbitrarily considering the fixed area as that of the fuselage below the vee tail and the movable area as that of one ruddervator.

Wind Tunnel and Testing Technique

The model tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is similar to that described in reference 3 for the Langley 15-foot free-spinning tunnel. The technique used for obtaining and converting data on the XP-88 model was the same as that used in reference 1. The drag coefficients of the parachutes used for the spin-recovery-parachute tests reported herein were measured at the time of the tests.

PRECISION

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

α, degrees	±1
ϕ, degrees	±1
V, percent	±5
Ω, percent	±2
Turns for recovery	$\pm\frac{1}{4}$ from motion-picture records $\pm\frac{1}{2}$ from visual observation

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

Comparison between model- and airplane-spin results (references 3 and 4) indicates that spin-tunnel results are not always in complete agreement with airplane-spin results. In general, the model spins at a somewhat smaller angle of attack, at a somewhat higher rate of descent, and with 5° to 10° more outward sideslip than the airplane. The comparison made in reference 4 showed that approximately 80 percent of the model-recovery tests predicted satisfactorily the corresponding airplane-recovery characteristics and that approximately 10 percent overestimated and 10 percent underestimated the airplane-recovery characteristics.

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

Weight, percent	0 low to 2 high
Center-of-gravity location, percent $\bar{c}$	1 forward to 1 rearward
I_X, percent	1 high to 5 high
I_Y, percent	1 high to 9 high
I_Z, percent	1 high to 10 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 ±1°.

TEST CONDITIONS

Tests were performed for the model conditions listed in table II. The mass characteristics and inertia parameters for loadings possible on the airplane and for the loadings of the model during tests are shown in table III. The inertia parameters for the loadings possible on the McDonnell XP-88 airplane and for the loadings tested on the model are also shown in figure 4. As discussed in reference 5, a plot such as figure 4 can be useful in predicting the relative effectiveness of the controls on the recovery characteristics of models.

The maximum control deflections used in the tests were as follows:

Rudder, degrees	20 right, 20 left
Elevator, degrees	25 up, 15 down
Ailerons, degrees	20 up, 20 down
Leading-edge flaps, degrees	30 down

Intermediate control deflections used were as follows:

Rudder, two-thirds deflected, degrees	$13\frac{1}{3}$
Elevator, two-thirds up, degrees	$16\frac{2}{3}$
Ailerons, one-third deflected, degrees	$6\frac{2}{3}$

RESULTS AND DISCUSSION

The results of the spin tests of the model are presented in charts 1 to 4 and in table IV. The model data are presented in terms of the full-scale values for the airplane at a test altitude of 15,000 feet. Unless otherwise stated, all tests were performed with the model in the clean condition (cockpit closed, flaps neutral, and landing gear retracted). Results for right and left spins were quite similar; therefore, only the results for right spins are presented.

Normal Loading

Erect spins.- The results of erect-spin tests of the model in the normal loading (loading point 1 in table III and figure 4) are shown in chart 1. The spin and recovery characteristics of the model were very satisfactory. The spins were generally wandering, but not very oscillatory, and were at fairly steep attitudes. Ailerons against the spin were slightly detrimental but only resulted in unsatisfactory recoveries when the stick was full forward.

Inverted spins.- The results of the inverted-spin tests of the model in the normal loading are presented in chart 2. The order used for presenting the data for inverted spins is the same as that of reference 1.

The inverted-spin-recovery characteristics of the model were generally satisfactory although it was indicated that for recovery, the stick should be maintained full forward. Recoveries could generally not be obtained with stick back which is believed due to the fact that both ruddervators were inside the vee and thus probably shielded and ineffective in stopping the spinning rotation.

Leading-Edge Flaps Deflected, Normal Loading

The results of tests with the leading-edge flaps deflected, normal loading, are presented in chart 3. The model either would not spin or recovered rapidly from all spins attempted. These recovery characteristics were slightly superior to those with the flaps neutral.

Long-Range Loading

Test results obtained with the model in the long-range loading (loading point 2 in table III and figure 4) are presented in chart 4. This loading was obtained by installing external wing-tip fuel tanks. The results show two conditions when the elevator was up. When the elevator was up, the model, when launched into the tunnel, continued to spin in the flat attitude at which it was launched for an abnormally long time but, in all cases, eventually, the model steepened and stopped spinning without the controls being moved. It was felt that this result was an indication that the airplane might have either or both conditions, one a flat spin, and the second a "no spin" and therefore the results are presented as two possible conditions. When recovery was attempted from the flat spin, recoveries by rudder reversal alone or by simultaneous rudder and elevator reversal were unsatisfactory. On the basis of these results, it is recommended that if the airplane enters a flat spin in the long-range loading and if recovery is not imminent soon after it is attempted, the tanks should be jettisoned and the recovery attempt repeated.

Spin-Recovery Parachutes

Results of spin-recovery-parachute tests are presented in table IV. A tail parachute, the equivalent of a full-scale parachute 10.0 feet in diameter with a towline 40 feet long, effected satisfactory recoveries of the model by parachute action alone.

Rudder Forces

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

Tests to determine the rudder forces were made in the same manner as that described in reference 1. Tests were made for the model in the normal loading, clean condition. The pedal force was found to be approximately 210 pounds from the model tests. Because of lack of detail in the rudder balance of the model, of inertia mass-balance effects, and of scale effect, this result is only a qualitative indication of the actual forces that may be experienced but it is believed to show that the forces encountered will be within the capabilities of the pilot.

Landing Condition

Tests were not made in the landing condition for the same reasons they were not made for the model with the conventional tail (reference 1).

RECOMMENDED RECOVERY TECHNIQUE

Based on results obtained with the model and upon general spin-tunnel experience, it is recommended that for erect spins the normal recovery technique be followed. That is, the rudder should be reversed briskly from full with the spin to full against the spin followed approximately one-half turn later by movement of the stick forward of neutral while maintaining it laterally neutral; care should be exercised to avoid excessive rates of acceleration in the recovery dive. For recovery from inverted spins, the stick should be maintained full forward while reversing the rudder.

COMPARISON OF CONVENTIONAL-TAIL AND VEE-TAIL RESULTS

A comparison of the test results obtained with the model with the conventional tail (reference 1) and with the vee tail indicates that the vee tail is superior in regard to spin and recovery characteristics. Normal loading, erect spins, with the ailerons neutral or with the spin, were similar for both tails; but when the ailerons were full against or as much as 1/3 against the spin, the recoveries were unsatisfactory with the conventional tail and satisfactory with the vee tail. When the model was in the long-range loading, the flat-type spin only occurred when the elevator was up with the vee tail, but it occurred for all elevator settings with the conventional tail. The recovery characteristics of the model from inverted spins were better with the conventional tail but, inasmuch as the recovery characteristics from inverted spins with the vee tail were considered satisfactory, this is not an important difference. There was little difference in the spin-recovery-parachute requirements or in the rudder pedal forces encountered. From the spinning viewpoint, therefore, it appears desirable that the airplane be equipped with the vee tail.

CONCLUSIONS

Based on results of spin tests of a $\frac{1}{24}$-scale model of the McDonnell XP-88 airplane with a vee tail, the following conclusions regarding the spin and recovery characteristics of the airplane at an altitude of 15,000 feet have been drawn:

1. Recoveries of the airplane from erect spins in the normal loading will be satisfactory. Recovery should be attempted by reversal of the rudder fully and rapidly, followed approximately one-half turn later by movement of the stick forward of neutral while maintaining it laterally neutral.

2. Recoveries from inverted spins will be satisfactory and should be made by rudder reversal while maintaining the stick full forward.

3. Recoveries from erect spins with the leading-edge flaps deflected were improved over those obtained with the flaps neutral.

4. Recoveries from erect spins in the long-range loading (external wing-tip tanks installed) may be unsatisfactory. If a spin is entered in this condition, recovery should be attempted immediately and, if recovery does not appear to be imminent, the tanks should be jettisoned.

5. A 10.0-foot-diameter tail parachute with a towline of 40 feet will be satisfactory for emergency recoveries from spins. This size is based on a drag coefficient of 0.63 for the laid-out-flat surface area.

6. The pedal forces necessary to move the rudders to effect satisfactory recovery will be within the physical capability of the pilot.

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Approved: Joseph A. Shortal
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MLE

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3. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. NACA Rep. No. 557, 1936.

4. Seidman, Oscar, and Neihouse, A. I.: Comparison of Free-Spinning Wind-Tunnel Results with Corresponding Full-Scale Spin Results. NACA MR, Dec. 7, 1938.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE MCDONNELL XP-88 AIRPLANE

Length over all, ft	54.25
Normal center-of-gravity location, percent $\bar{c}$	19.6
Wing:	
Span, ft	39.67
Area, sq ft	350
Sweepback at c/4, deg	35
Incidence, deg	1
Dihedral, deg	0
Section	NACA 65_1-009
Aspect ratio	4.50
Mean aerodynamic chord, $\bar{c}$ in.	117.2
Leading edge of $\bar{c}$ rearward of leading edge of root chord, in.	82.0
Ailerons:	
Area, sq ft	18.4
Span, percent b/2	37.8
Hinge-line location, percent wing chord	75
Tail:	
Area in chord plane, sq ft	92.0
Area in vertical projection, sq ft	59.1
Area in horizontal projection, sq ft	70.4
Ruddervator area aft of hinge line in chord plane, sq ft	24.0
Dihedral, deg	40
Incidence, deg	0
Sweepback at c/4, deg	35
Distance from normal center of gravity to ruddervator hinge line at intersection of vee, ft	26.09
Tail-damping power factor	1709×10^{-6}

TABLE II.- CONDITIONS TESTED ON THE $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-88 AIRPLANE WITH VEE TAIL INSTALLED

[Flaps and landing gear retracted unless otherwise noted; right spins]

Type of spin	Condition	Loading	Parachutes	Data presented on		Figure
				Chart	Table	
Erect	Clean	Normal	----	1	--	1, 2
Inverted	Clean	Normal	----	2	--	1, 2
Erect	Leading-edge flaps deflected	Normal	----	3	--	----
Erect	External full tanks installed	Long range	----	4	--	----
Erect	Clean	Normal	Tail	-	IV	----

TABLE III.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADING CONDITIONS POSSIBLE ON THE MCDONNELL XP-88 AIRPLANE AND FOR THE LOADINGS TESTED ON THE $\frac{1}{24}$-SCALE MODEL WITH VEE TAIL INSTALLED

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

Number (Same as fig. 3)	Loading	Weight (lbs)	Center-of-gravity location		Relative airplane density (μ)		Moments of inertia (slug-ft^2)			Mass parameters		
			$x/\bar{c}$	$z/\bar{c}$	Sea level	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	Normal	16,567	0.196	0.067	15.6	24.8	12,211	42,218	51,888	-370×10^{-4}	-119×10^{-4}	489×10^{-4}
2	Long range	21,154	.330	.046	19.9	31.6	75,376	48,591	121,080	259	-698	439
Model values												
1	Normal	16,681	0.206	0.061	15.7	24.9	12,604	43,748	53,890	-388×10^{-4}	-126×10^{-4}	515×10^{-4}
2	Long range	21,268	.350	.047	20.0	31.8	82,876	48,564	128,888	335	-786	450

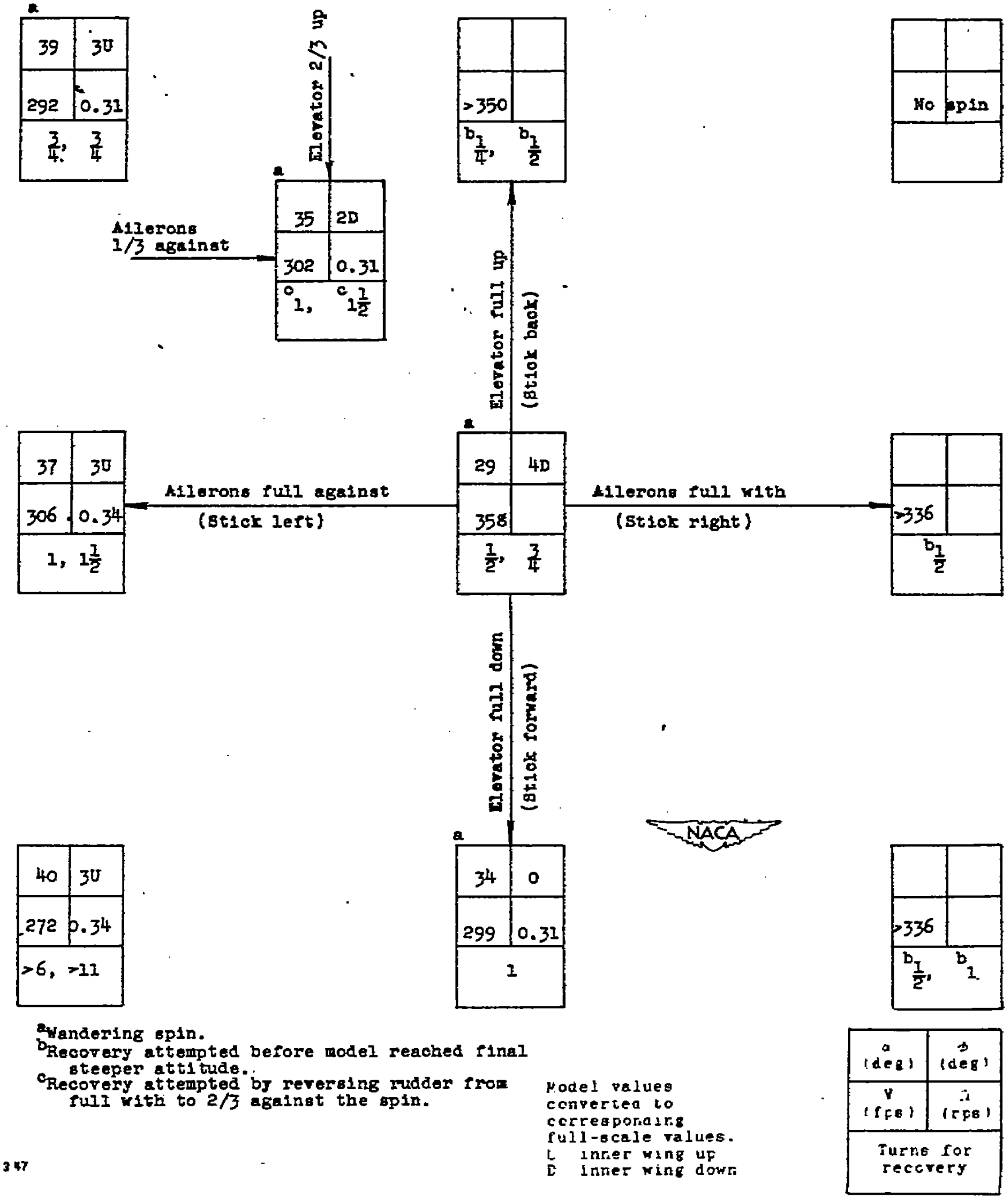
TABLE IV.- SPIN-RECOVERY TAIL-PARACHUTE DATA OBTAINED WITH THE $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-88 AIRPLANE WITH VEE TAIL INSTALLED

[Loading point 1 on table III and figure 4; rudder fixed full with the spin; model values converted to corresponding full-scale values; C_D of parachutes 0.63; right erect spins]

Parachute diameter (ft)	Towline length (ft)	Stick position	Turns for recovery
7.0	40.0	1/3 against and 2/3 back	$\frac{3}{4}$, $1\frac{1}{4}$, $2\frac{1}{2}$
8.0	40.0	-----------do-----------	$\frac{3}{4}$, 1, >5
10.0	40.0	-----------do-----------	$\frac{3}{4}$, $1\frac{1}{2}$, $1\frac{1}{2}$, 2
12.0	40.0	-----------do-----------	$\frac{3}{4}$, $1\frac{1}{4}$, $1\frac{1}{2}$

CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-85 AIRPLANE WITH VEE TAIL INSTALLED IN THE NORMAL LOADING

[Loading point 1 on table III and figure 4; all flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from and steady-spin data presented for, rudder-with spins); right erect spins]



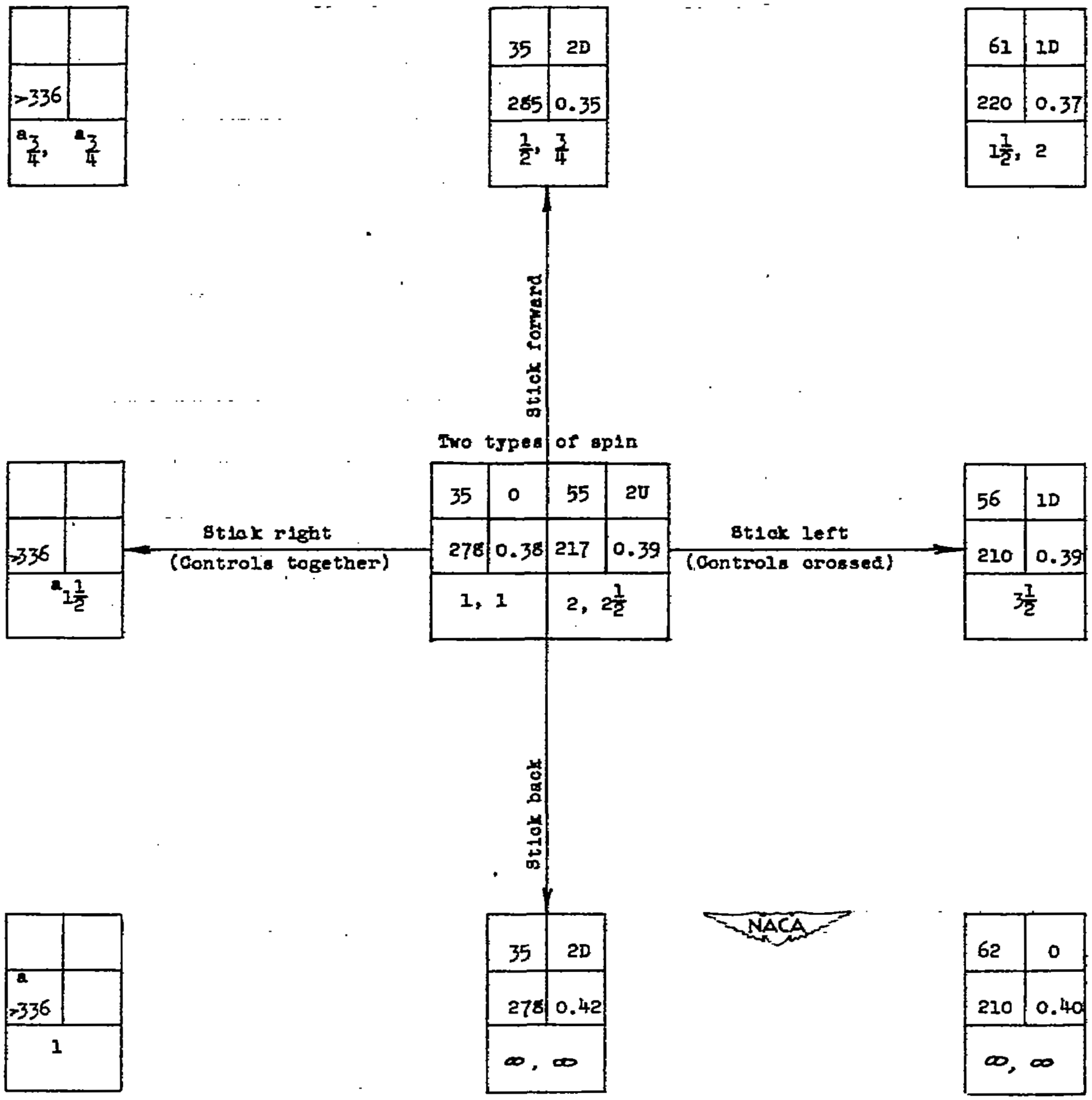
[a] Wandering spin.

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

[c] Recovery attempted by reversing rudder from full with to 2/3 against the spin.

CHART 2.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-85 AIRPLANE WITH VEE TAIL INSTALLED IN THE NORMAL LOADING

[Loading point 1 on table III and figure 4; all flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-with spins); rotation to pilot's right]



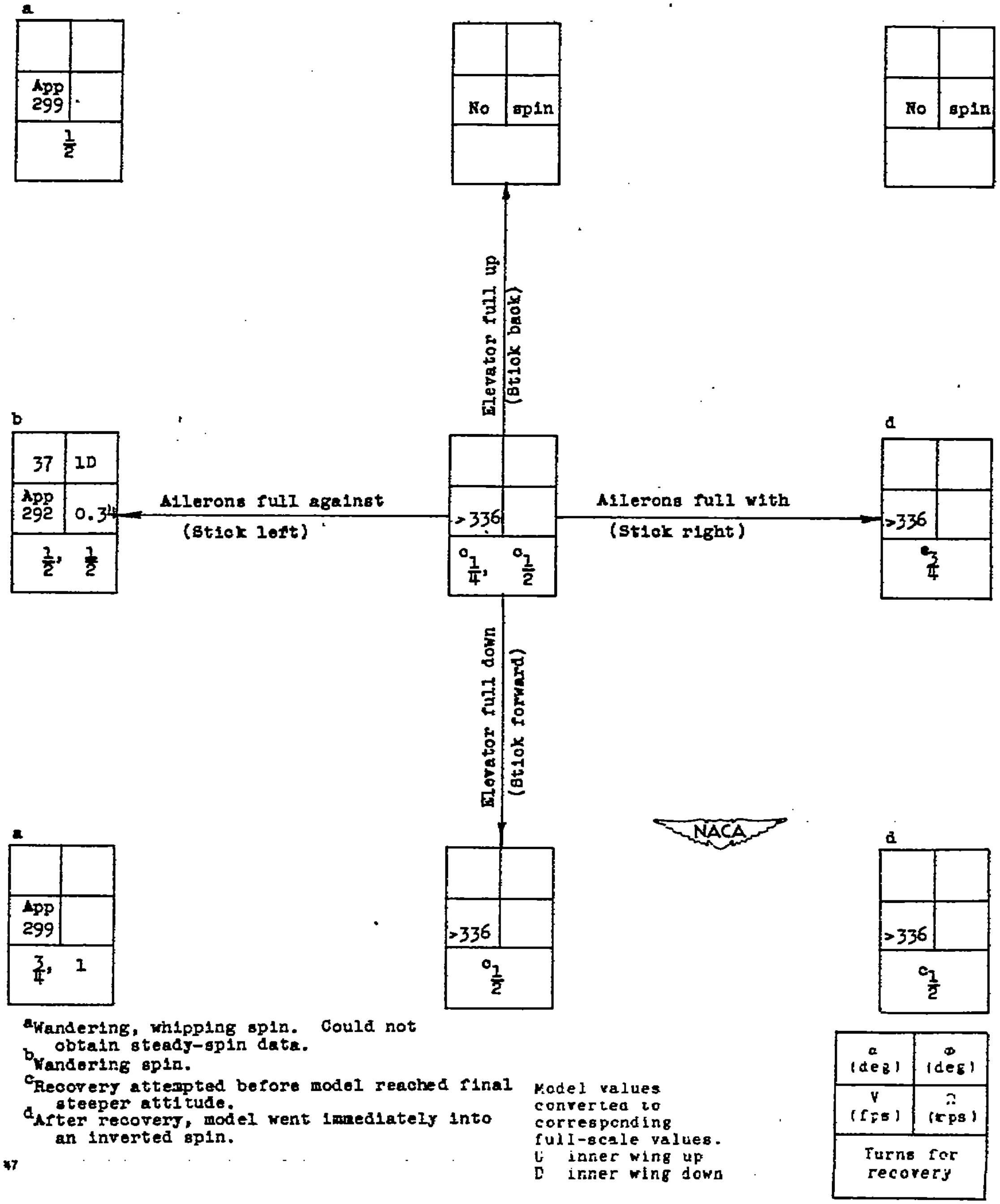
^{a}Recovery attempted before model reached final steeper attitude.

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

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

CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-88 AIRPLANE WITH VEE TAIL INSTALLED WITH THE LEADING-EDGE FLAPS DEFLECTED 30°

[Normal loading (point 1 on table III and figure 4); trailing-edge flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-with spins); right erect spins]



[a] Wandering, whipping spin. Could not obtain steady-spin data.
[b] Wandering spin.
[c] Recovery attempted before model reached final steeper attitude.
[d] After recovery, model went immediately into an inverted spin.

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

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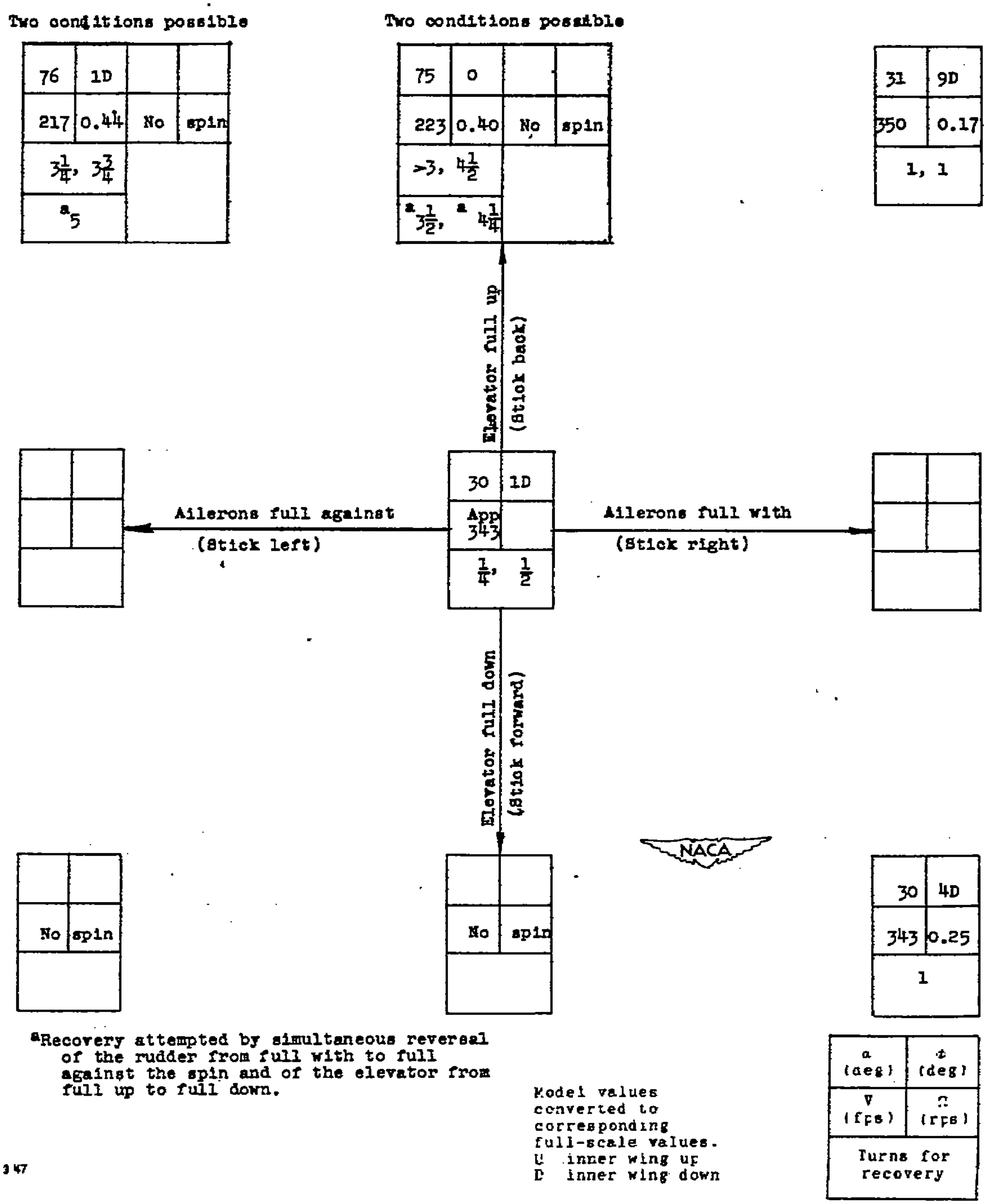
CHART 4.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{24}$-SCALE MODEL OF THE MCDONNELL XP-85 AIRPLANE WITH VEE TAIL INSTALLED IN THE LONG-RANGE LOADING (WING-TIP FUEL TANKS INSTALLED)

[Loading point 2 on table III and figure 5; all flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-with spins); right erect spins]



[a] Recovery attempted by simultaneous reversal of the rudder from full with to full against the spin and of the elevator from full up to full down.

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

3 47

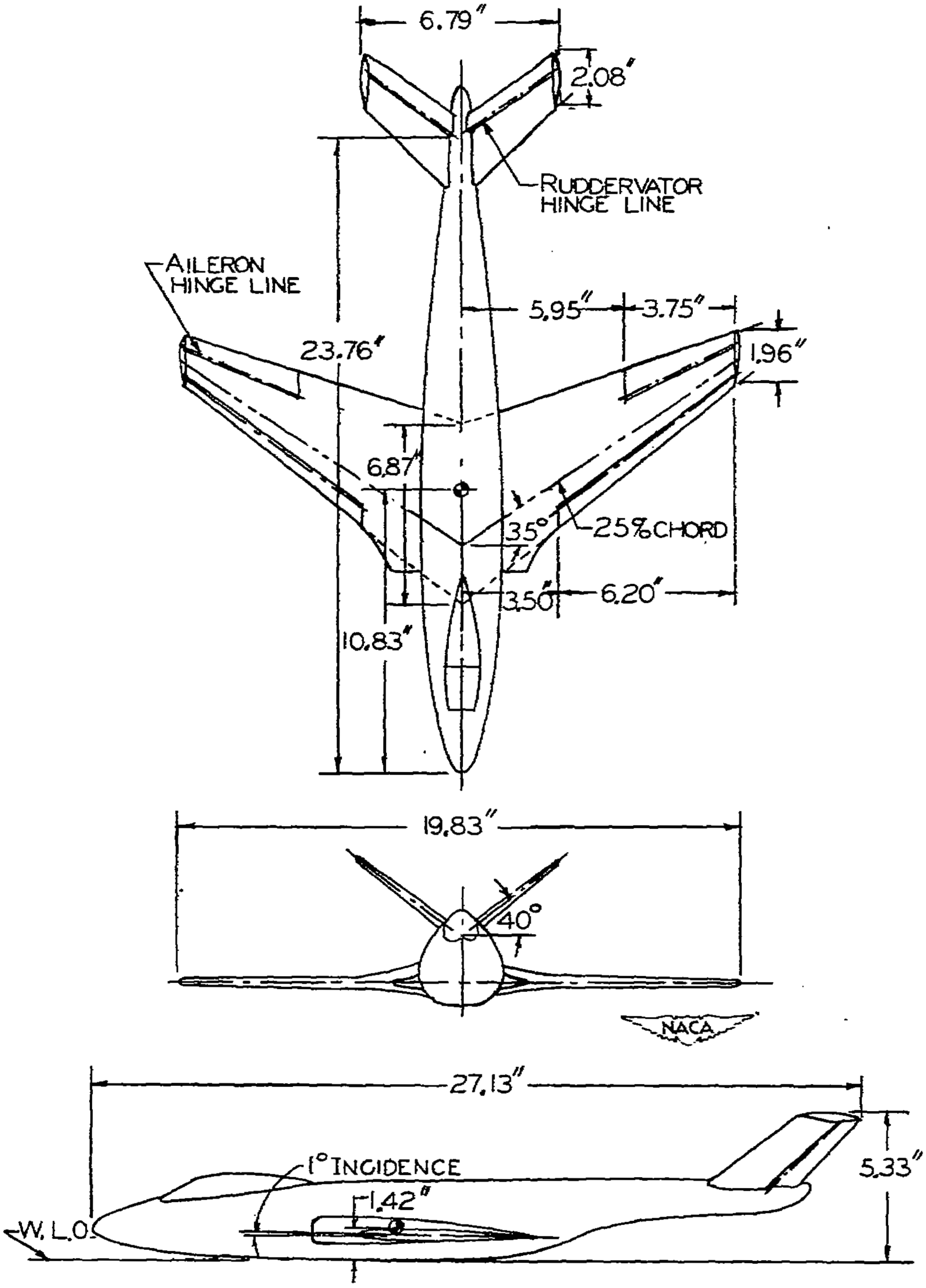


FIGURE 1.- THREE-VIEW DRAWING OF THE $\frac{1}{24}$-SCALE MODEL OF THE McDONNELL XP-88 AIRPLANE TESTED IN THE 20-FOOT FREE-SPINNING TUNNEL. CENTER OF GRAVITY SHOWN FOR THE NORMAL LOADING. VEE TAIL INSTALLED.

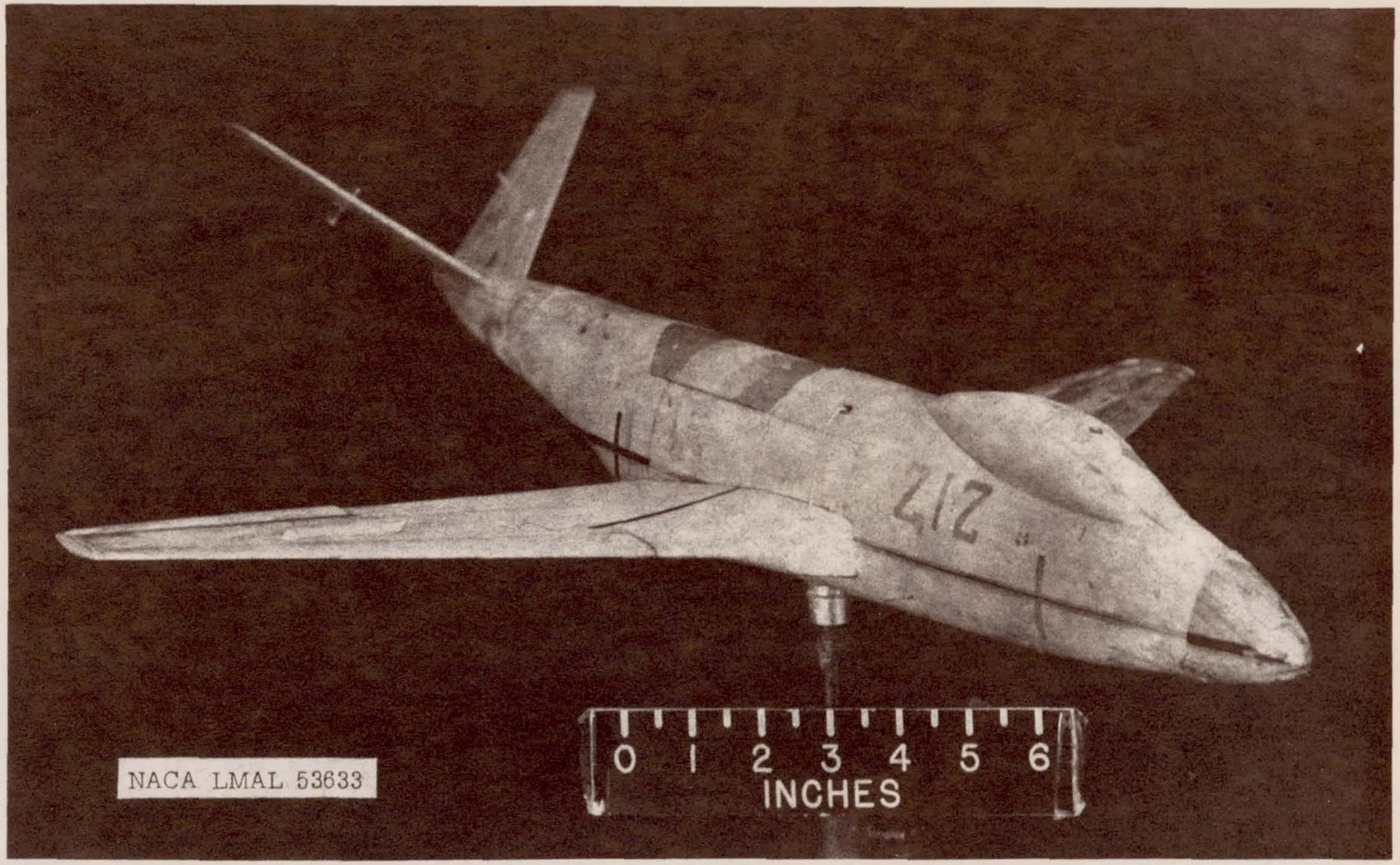


Figure 2.- The $\frac{1}{24}$-scale model of the McDonnell XP-88 airplane with vee tail installed.

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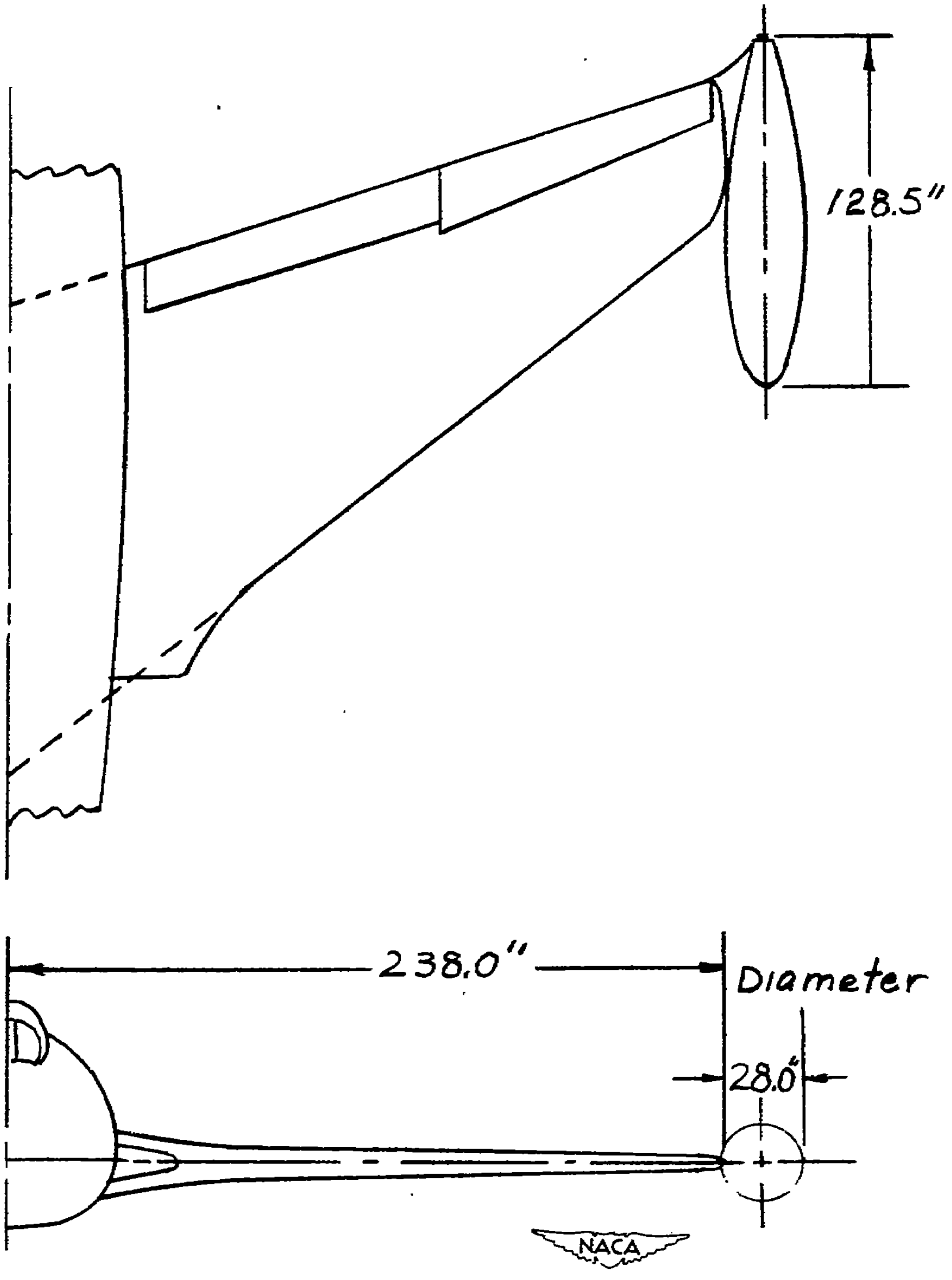

Figure 3. -Sketch showing installation of wingtip fuel tanks. Dimensions are full-scale values.

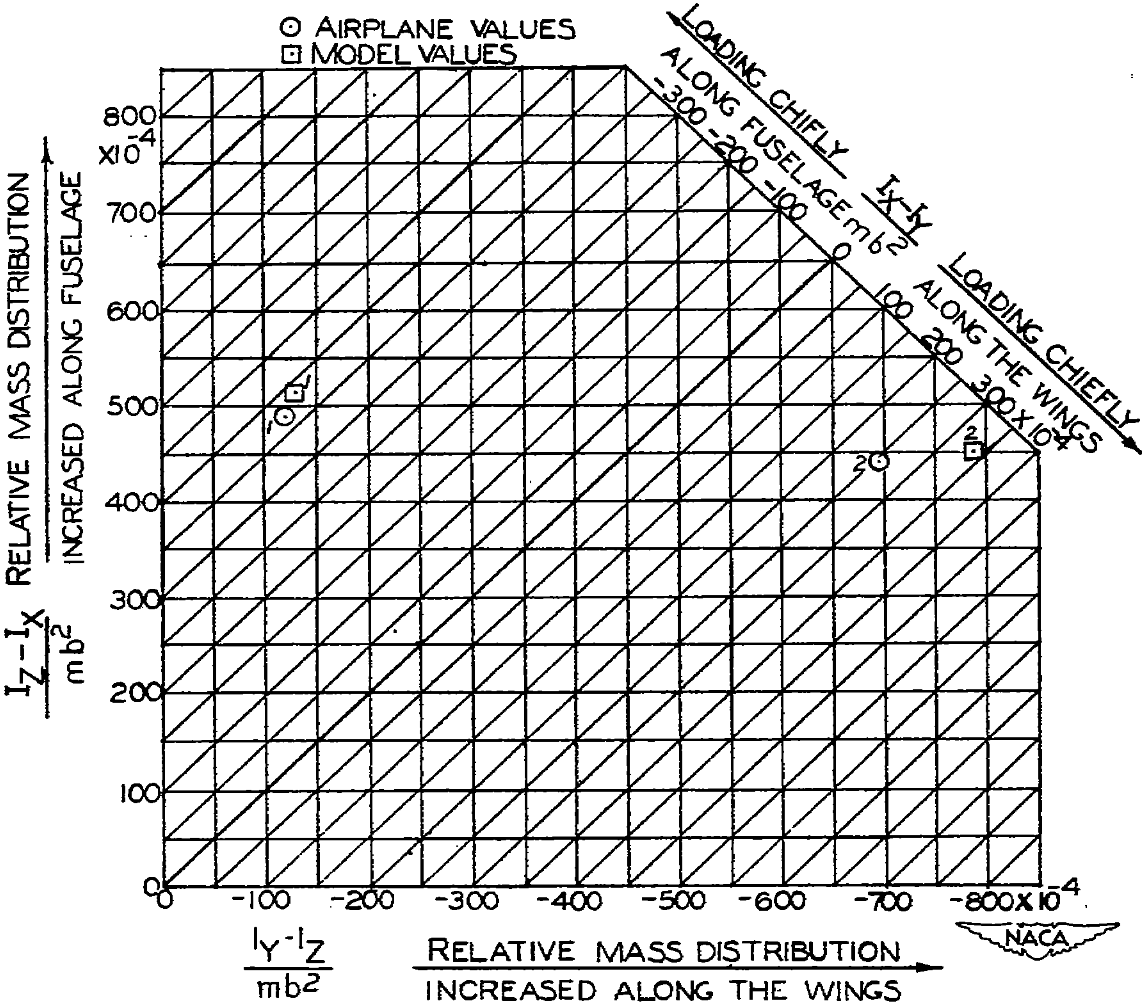

FIGURE 4.-INERTIA PARAMETERS FOR LOADINGS OF THE McDONNELL XP-88 AIRPLANE AND FOR THE LOADINGS TESTED ON THE $\frac{1}{24}$-SCALE MODEL. (POINTS ARE FOR LOADINGS LISTED IN TABLE III). *VEE TAIL INSTALLED.*