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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{29}$-SCALE MODEL OF THE REPUBLIC XP-91 AIRPLANE WITH A VEE TAIL INSTALLED

By

Thomas L. Snyder

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{29}$-SCALE MODEL OF THE REPUBLIC XP-91 AIRPLANE WITH A VEE TAIL INSTALLED

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SUMMARY

A spin investigation has been conducted in the Langley 20-foot free-spinning tunnel on a $\frac{1}{29}$-scale model of the Republic XP-91 airplane with a vee tail installed. The effects of control settings and movements upon the erect spin and recovery characteristics of the model were determined for the clean condition (wing tanks removed, landing gear and flaps retracted). The tests were made at a loading simulating that following cruise at altitude and at a time when nearly all fuel was expended.

The results indicated that the airplane might not spin at normal spinning-control configuration, but if a spin were obtained, recovery therefrom by full rudder reversal would be satisfactory. It was also indicated that aileron-against settings would lead to violent oscillatory motions and should be avoided.

INTRODUCTION

In accordance with a request by the Air Materiel Command, Army Air Forces, tests were performed in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of a $\frac{1}{29}$-scale model of the Republic XP-91 airplane equipped with a vee tail. The airplane is a single-place rocket-jet fighter with a sweptback wing of variable incidence and inverse taper ratio.

Prior to conducting the spin-tunnel investigation, the Republic Aviation Corporation informed Langley that the vee tail designed for the airplane was to be replaced by a conventional tail. It was felt, however, that brief tests with the vee tail installed would be of interest especially

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inasmuch as only meager spin data are available for vee-tail installations. Directional and longitudinal control is obtained by means of surfaces known as ruddervators. The ruddervators are controlled by longitudinal movement of the control column and by rudder-pedal movement. A longitudinal movement of the stick deflects the surfaces equally in the same direction; whereas, a rudder-pedal movement deflects one surface up and the other surface down. The control column and rudder pedals are so linked that it is possible to obtain maximum rudder-pedal deflection for all positions of the control column; and, conversely, it is possible to obtain maximum control column movement for all positions of the rudder pedals. In order to simplify the discussion herein elevator deflections and rudder deflections will be used to designate longitudinal movement of the control column and movement of the rudder pedals, respectively.

The tests were performed for the clean condition of the airplane (external wing tanks removed, landing gear retracted, and flaps retracted) for the loading simulating that following cruise at altitude when nearly all fuel is expended. For the tests, the wing incidence was adjusted for cruise flight (0° incidence). In an attempt to improve the directional stability characteristics of the airplane, the Republic Aircraft Corporation decided to move the tail surfaces of the airplane rearward 55 inches from their original location, and the model as tested represented the airplane configuration with the tail surfaces moved rearward.

SYMBOLS

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 thrust line 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
$\frac{I_X - I_Y}{mt^2}$	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 between thrust line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, rps
σ	helix angle, angle between flight path and vertical, degrees (For tests of this model, the average absolute value of helix angle was approximately 8°.)
β	approximate angle of sideslip at center of gravity, degrees (Sideslip is inward when inner wing is down by an amount greater than helix angle.)

APPARATUS AND METHODS

Model

The $\frac{1}{29}$-scale model of the Republic XP-91 airplane was built by the Hampton Roads Model Company and prepared for testing by the Langley Laboratory. A three-view drawing of the model in the clean condition with external wing tanks removed and flaps and landing gear retracted is shown in figure 1. Dimensional characteristics of the airplane are presented in table I. A photograph of the model as tested is shown in figure 2.

The tail-damping power factor was, in general, computed by the method described in reference 1. It was arbitrarily assumed, however, that for the vee tail the fuselage side area below the tail-surface intersection and the projected area of one ruddervator on the plane of symmetry were effective in opposing the spin rotation.

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/cu ft). A remote-control mechanism was installed in the model to actuate the controls for recovery tests. Sufficient moments were exerted on the control surfaces during recovery tests to reverse the controls fully and rapidly.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is, in general, similar to the operation described in reference 2 for the Langley 15-foot free-spinning tunnel, except that the model-launching technique has been changed. With the controls set in the desired position, the model is launched by hand with rotation into the vertically rising air stream. After a number of turns in the established spin, during which time the model is maintained at eye level by the force of the rising air, recovery is attempted by moving one or more controls by means of a remote-control mechanism. After recovery the model dives into a safety net.

The spin data presented were determined and converted from model values to corresponding full-scale values by methods described in reference 2. Spin-tunnel tests are made to determine the spin and recovery characteristics of the model for the normal-control configuration for spinning (elevator full-up, ailerons neutral, and rudder full with the spin) and at various other aileron-elevator control combinations including zero and maximum deflections. Recovery is generally attempted by rapid full rudder reversal. Tests are also performed to evaluate the possible adverse effects on recovery of small deviation from the normal-control configuration for spinning. For these tests, the ailerons are set at one-third of the full deflection in the direction conducive to slower recoveries (against the spin for this model), and the elevator is set at two-thirds of its full-up deflection. Recovery is attempted by either rapidly reversing the rudder from full with the spin to two-thirds against the spin or by movement of the rudder to two-thirds against the spin in conjunction with moving the elevator to one-third down. This control configuration and movement is referred to as the "criterion spin." Recovery characteristics of the model are considered satisfactory if recovery from this criterion spin requires $2\frac{1}{4}$ turns or less by rudder reversal or by combination of rudder and elevator reversal. This value has been selected on the basis of full-scale airplane spin-recovery data that are available for comparison with corresponding model results.

For spins which have a rate of descent in excess of that which can be readily attained in the tunnel, the rate of descent is recorded as greater than the velocity at the time the model hits the safety net, for example, greater than 300 feet per second. For these tests, the recovery is generally attempted before the model reaches its final steeper attitude and while the model is still descending in the tunnel. Such results are conservative; that is, recoveries are not as fast as those for which the model is in the final steeper attitude. For recovery attempts in which the model strikes the safety net while it is still in a spin, the recovery is recorded as greater than the number of turns from the time the controls are moved to the time the model strikes the net, as greater than 4. A greater than 4-turn recovery, however, does not necessarily indicate an improvement over a greater than 7-turn recovery. When the model recovers without control movement, with the rudder set with the spin, the result is recorded as "no spin."

PRECISION

The model test results presented 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	$\pm\frac{1}{4}$ from motion-picture records $\pm\frac{1}{2}$ from visual observation

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

Comparison between model and full-scale results (references 2 and 3) indicates that spin-tunnel results are not always in complete agreement with airplane-spin results. In general, the models spun at a somewhat smaller angle of attack, at a somewhat greater rate of descent, and at 5° to 10° more outward sideslip than did the corresponding airplanes. The comparison made in reference 3 for 20 airplanes showed that approximately 80 percent of the models predicted satisfactorily the number of turns required for recovery from the spin for the corresponding airplanes and that approximately 10 percent overestimated and approximately 10 percent underestimated the number of turns required.

Because it is impracticable to ballast the model exactly and because of the inadvertent damage to the model during tests, the measured weight and mass distribution of the XP-91 model varied from the true scaled-down values within the following limits:

Weight, percent		0 to 2 high
Center-of-gravity location, percent $\bar{c}$		0 to 1 rearward
Moments of inertia	I_X	2 high to 4 high
	I_Y	1 high to 6 high
	I_Z	1 high to 5 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

Controls were set with an accuracy of ±1°.

TEST CONDITIONS

At the time the model was prepared for spin tests, the mass information available for the airplane was for the condition before the tail surfaces were moved rearward 55 inches. The variations in the airplane weight, center-of-gravity location, and moments of inertia due to moving the tail surfaces rearward were, however, estimated by the Langley Laboratory and the available mass information was corrected accordingly.

Inasmuch as the Republic Aircraft Corporation indicated that the airplane would probably not be flown with the vee tail installed, only brief tests were performed, therefore, at only one loading condition of the airplane in order to prevent damaging the model beyond use for probable subsequent tests with a conventional tail installed. The tests were arbitrarily performed for the loading condition with nearly all fuel and ammunition expended, which Republic indicated to be representative of the loading of the airplane following the operational flight at 50,000 feet. The mass characteristics and inertia parameters for the loadings possible on the airplane and for the loading tested on the model are listed on table II. The inertia parameters are also plotted in figure 3. As discussed in reference 4, figure 3 can be used as an aid in predicting the relative effectiveness of the controls on the recovery characteristics of the airplane.

The maximum control deflections used in the tests were the following:

Elevator, degrees	25 up, 19 down
Rudders, degrees	±8
Ailerons, degrees	20 up, 18 down

Intermediate control deflections used were the following:

Elevator, two-thirds deflected up, degrees	$10\frac{2}{3}$
Rudders, two-thirds deflected, degrees	$\pm5\frac{1}{3}$
Ailerons, one-third deflected, degrees	$6\frac{2}{3}$ up, 6 down

As previously mentioned, the rudder pedals and control column are so linked that it is possible to obtain maximum rudder-pedal movement for all positions of the control column; and conversely, it is possible to obtain maximum control-column movement for all positions of the rudder pedals. For example, with the control column full back (both surfaces deflected 25° up) and pushing the right rudder pedal forward deflects the surfaces $\pm8^\circ$ about the elevator position; that is, the right surface travels to 17° up and the left surface travels to 33° up.

RESULTS AND DISCUSSION

The results of the spin tests of the model are presented in chart 1. The model data are presented in terms of the full-scale values for the airplane at a test altitude of 15,000 feet.

Preliminary tests of the model showed that left and right spins were similar. The results are arbitrarily presented in terms of equivalent right spins, that is, for the airplane turning to the pilot's right.

Clean condition.- The test results obtained with the XP-91 model in the clean condition (external wing tanks removed, landing gear and flaps retracted) with nearly all fuel and ammunition expended are presented in chart 1. The model loading condition is represented by point 3 on table II and figure 3. For the normal-control configuration for spinning (elevators full up, ailerons neutral, and rudders full with the spin) the model would not spin; that is, after the rotation imparted to the model during launching was expended, the model recovered in a steep dive. Setting the controls for the criterion-spin configuration led to a steep spin ($\alpha = 32^\circ$ approximately) from which recovery was satisfactory by either reversing the rudders from full with the spin to two-thirds against the spin or by moving the elevators to one-third down in conjunction with reversing the rudder from full with to two-thirds against the spin. Setting the elevators to neutral or full down when the ailerons were neutral led to steep wandering spins. Rapid full rudder reversal effected satisfactory recovery followed by a steep dive from the spins obtained with the elevators set at neutral. Although recovery was not attempted from the spin obtained with the elevators set down, it is felt that recovery by rudder reversal would have been satisfactory because the model spin attitude was similar to that for the elevator-neutral spin.

When the ailerons were set full against the spin, regardless of the elevator position, the model became extremely oscillatory in pitch, yaw, and roll after the rotation imparted to the model during launching was expended. The attitudes of the fusleage varied from very flat angles to very steep angles, and the wing simultaneously rolled through a large range of angles. When the outboard wing dropped down, the fuselage was nearly horizontal and the model slipped outward; then, the model would pick up the outboard wing, and simultaneously the nose dropped down, and the inboard wing yawed forward. At times, when the outboard wing was down, the model would become inverted, and then return to the erect attitude after a few turns with a continuation of the extreme oscillations, and at times the model appeared to enter a left roll. The airspeed varied from 231 to 291 feet per second (full scale) during the spin. When the rudders were reversed against the rotation while the model was erect, the model continued to oscillate in a manner similar to when the rudders were set with the rotation.

With the ailerons set full with the spin and elevators full-up, the model would not continue to spin after the rotation imparted during launching was expended. Setting the elevator to neutral led to a steep spin with a rate of descent in excess of that readily attainable in the tunnel. Recovery attempted before the model reached its final steeper attitude by rapid full rudder reversal was satisfactory.

The preceding results indicate that aileron-against settings should be avoided and that the normal-control manipulation for recovery - rapid full rudder reversal followed 1/2 turn later by movement of the stick forward of neutral - produces rapid recoveries. Also, an analysis of the preceding results indicates that the probable spin-recovery characteristics of the airplane at 15,000 feet will also be satisfactory for the other loadings possible on the airplane.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of spin tests of a $\frac{1}{29}$-scale model of the Republic XP-91 airplane with a vee tail installed, the following conclusions and recommendations regarding the spin and recovery characteristics of the airplane at 15,000 feet are made:

1. The recovery characteristics of the airplane will be satisfactory.

2. For recovery from erect spins, the rudders should be reversed to full against the spin followed approximately 1/2 turn later by movement of the stick forward of neutral, avoiding aileron-against settings.

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

Thomas L. Snyder
Thomas L. Snyder
Aeronautical Engineer

Approved: Thomas A. Harris

Thomas A. Harris
Chief of Stability Research Division

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF XP-91 AIRPLANE WITH VEE-TAIL INSTALLATION

Length, over all, ft	51.21
Wing:	
Span, ft	31.34
Area, sq ft	216.5
Section, root	Republic R-4,40-1710-1.0
Section, tip	Republic R-4,40-10-1.0
Root-chord incidence, deg	0
Tip-chord incidence, deg	0
Aspect ratio	4.54
Taper ratio	1.62
Sweepback of 50-percent-chord line, deg	40
Dihedral of wing, deg	0
Mean aerodynamic chord, in.	127.02
Leading edge $\bar{c}$ aft of leading-edge root chord, in.	69.08
Ailerons:	
Total area, sq ft	45.56
Total area aft of hinge line, sq ft	37.62
Mean chord, percent of $\bar{c}$	36.0
Span, percent of b/2	17.4
Vee tail:	
Total area, sq ft	81.4
Ruddervator area, sq ft	19.72
Dihedral, deg	38
Sweepback of leading edge, deg	40
Tail-damping power factor	4324×10^6

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TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADINGS POSSIBLE ON THE XP-91 AIRPLANE AND FOR LOADING TESTED ON THE MODEL

[Moments of inertia are given about the center of gravity of the airplane]

Number	Loading	Weight (lb)	μ, sea level	μ, 15,000 ft	Center-of-gravity location		Moments of inertia			Mass parameters		
					$x/\bar{c}$	$z/\bar{c}$	I_X (slug-ft^2)	I_Y (slug-ft^2)	I_Z (slug-ft^2)	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane values												
1	Take-off gross weight	28,991	55.8	88.7	0.183	0.063	29,283	64,721	88,229	-403×10^{-4}	-267×10^{-4}	670×10^{-4}
2	Gross weight	18,192	35.1	55.7	.190	-.035	15,491	55,109	68,495	-714	-242	956
3	Nearly all fuel and ammunition expended	14,172	27.27	43.3	.26	-.013	15,234	47,108	60,632	-738	-313	1051
Model values converted to corresponding full-scale values												
3	Nearly all fuel and ammunition expended	14,155	27.25	43.31	0.262	-0.027	15,552	47,147	61,153	-732×10^{-4}	-325×10^{-4}	1057×10^{-4}

CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{29}$-SCALE MODEL OF THE REPUBLIC XP-91 AIRPLANE; VEE TAIL INSTALLED

[Loading following cruise at altitude (nearly all fuel and ammunition expended). Point 3 on table II; Recovery attempted by rapid full rudder reversal except as indicated (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); right erect spins]

Model became extremely oscillatory in pitch, yaw, and roll. When the outboard wing was down 90°, the model became inverted.

After the initial rotation due to launching was expended, the model dived out in a steep glide.

After the initial rotation due to launching was expended, the model dived out in a steep glide.

Steep spin
Angle of attack: 32°
Rate of rotation: 0.18
Vertical velocity: 291

Rudder reversed to $\frac{2}{3}$ against the spin — 1, dives out; $1\frac{1}{4}$, dives out

Rudder reversed to $\frac{2}{3}$ against the spin and the elevator to $\frac{1}{3}$ down — $\frac{1}{2}$, dives out; $\frac{1}{2}$, dives out

Model became extremely oscillatory in pitch, yaw, and roll. When the outboard wing was down 90°, the model became inverted.

Steep spin, model wandered with a whip
Angle of attack approximated 27°
Vertical velocity: 268

Full rudder reversal — $\frac{1}{2}$, dives out; $1\frac{1}{2}$, dives out

Steep spin. The rotation nearly ceased, then model whipped and repeated the motion
Vertical velocity: > 385

Full rudder reversal — $\frac{1}{4}$, dives out

Model became extremely oscillatory in pitch, yaw, and roll. When the outboard wing was down 90°, the model became inverted.

Steep spin. Model wandered with a whip
Angle of attack approximately 21°
Vertical velocity: 410

Key to control settings

Ailerons full against Elevator up	Ailerons neutral Elevator up	Ailerons full with Elevator up
	Ailerons $\frac{1}{3}$ against Elevator $\frac{2}{3}$ up	
Ailerons full against Elevator neutral	Ailerons neutral Elevator neutral	Ailerons full with Elevator neutral
Ailerons full against Elevator down	Ailerons neutral Elevator down	Ailerons full with Elevator down

Key to results

Description of steady spin (rudder with the spin).
Approximate angle of attack
Rate of rotation rps, (full scale)
Vertical velocity, ft/sec (full scale)

Number of turns required for recovery
Recovery attempted by full rudder reversal unless indicated otherwise

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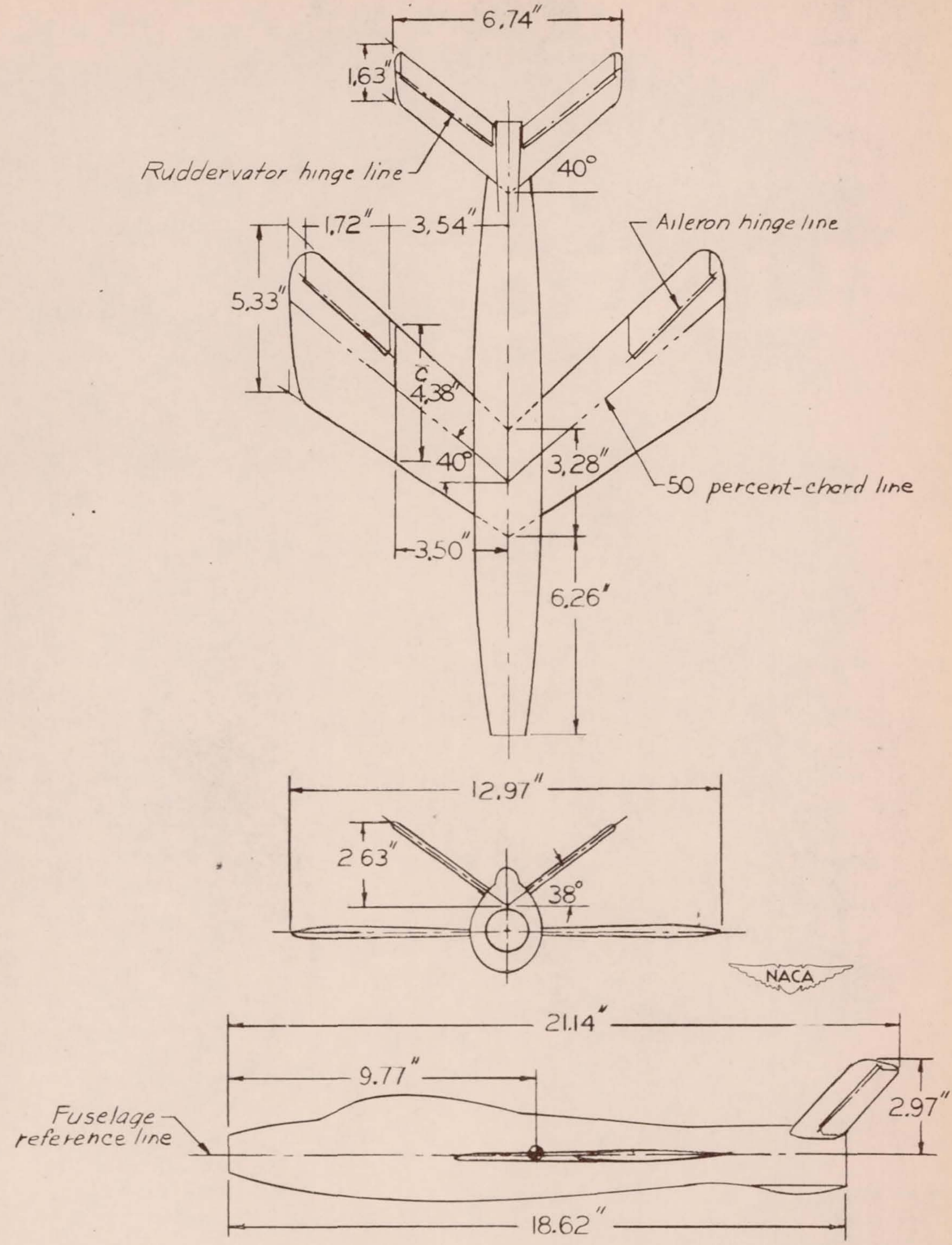

Figure 1. - Drawing of the $\frac{1}{29}$-scale model of the Republic XP-91 airplane as tested in the free-spinning tunnel. Center of gravity indicated for loading condition following cruise at altitude. Vee tail installed.

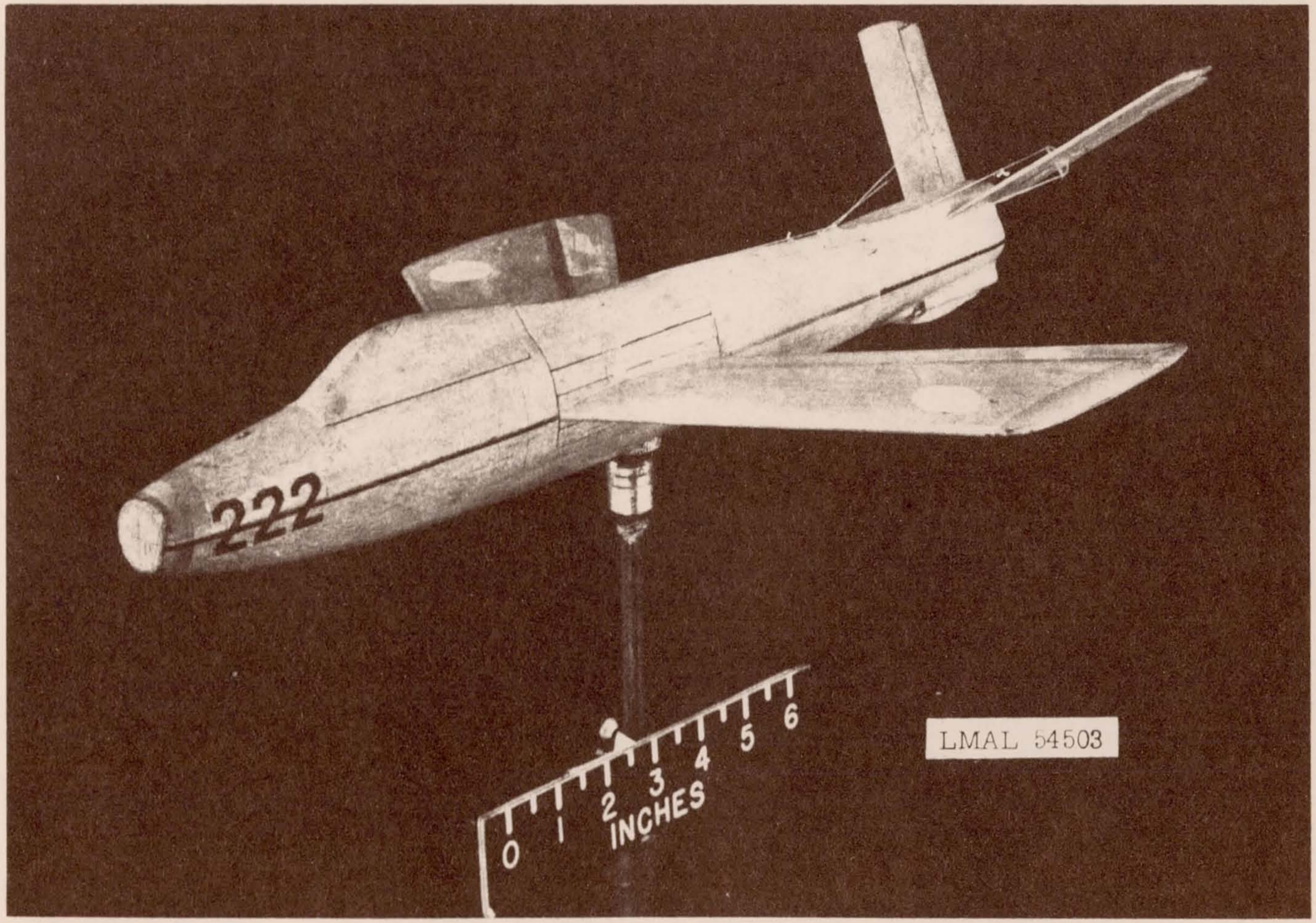

Figure 2.- Photograph of $\frac{1}{29}$-scale model of Republic XP-91 airplane with vee tail installed. Clean condition; external wing tanks removed; flaps and landing gear retracted.

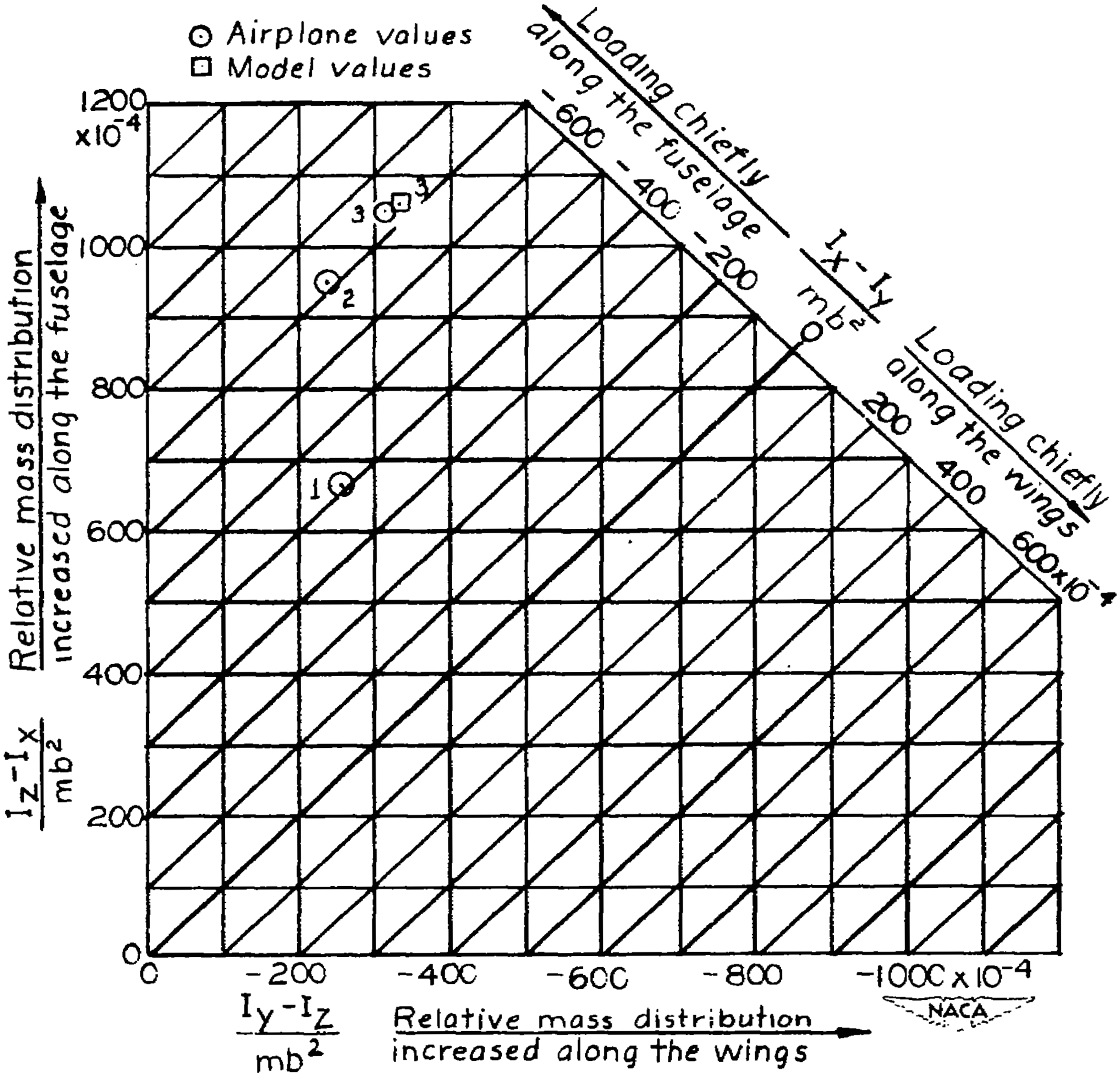

Figure 3.- Mass parameters for loadings possible on the XP-91 airplane and for loading tested on the model. (Points are for loadings listed in table II.)