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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING-TUNNEL INVESTIGATION OF A $\frac{1}{24}$ - SCALE

MODEL OF THE GRUMMAN F9F-6 AIRPLANE

TED NO. NACA DE 364

By Walter J. Klinar and Frederick M. Healy

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Langley Field, Va.

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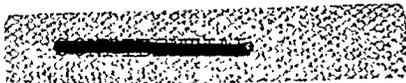
SUMMARY

An investigation of a $\frac{1}{24}$ - scale model of the Grumman F9F-6 airplane has been conducted in the Langley 20-foot free-spinning tunnel. The erect and inverted spin and recovery characteristics of the model were determined for the normal flight loading with the model in the clean condition. The effect of loading variations was investigated briefly. Spin-recovery parachute tests were also performed.

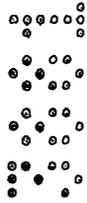
The results indicate that erect spins obtained on the airplane in the clean condition will be satisfactorily terminated for all loading conditions provided full rudder reversal is accompanied by moving the ailerons and flaperons (lateral controls) to full with the spin (stick right in a right spin). Inverted spins should be satisfactorily terminated by full reversal of the rudder alone. The model tests indicate that an 11.4-foot (laid-out-flat diameter) tail parachute (drag coefficient approximately 0.73) should be effective as an emergency spin-recovery device during demonstration spins of the airplane provided the towline is attached above the horizontal stabilizer.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, a spin investigation has been made in the Langley 20-foot



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free-spinning tunnel of a $\frac{1}{24}$ -scale model of the Grumman F9F-6 airplane. The F9F-6 differs from the model of the straight-wing XF9F-2 airplane previously investigated in the spin tunnel and reported in reference 1 primarily in that the wing and the horizontal tail surfaces have been swept back 35° at the quarter-chord line.

The erect and inverted spin and recovery characteristics of the F9F-6 model in the normal flight loading were determined. The investigation also included parachute-recovery tests and brief tests to determine the effect of loading variations.

SYMBOLS

b	wing span, ft
m	mass of airplane, slugs
\bar{c}	mean aerodynamic chord, ft
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 line)
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-ft 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/cu ft
α	angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg



ϕ	angle between span axis and horizontal, deg
V	full-scale true rate of descent, ft/sec
Ω	full-scale angular velocity about spin axis, rps

APPARATUS AND METHODS

Model

The $\frac{1}{24}$ -scale model of the Grumman F9F-6 airplane was furnished by the Bureau of Aeronautics and was prepared for testing by the Langley Laboratory of the National Advisory Committee for Aeronautics. A three-view drawing of the model as tested is shown in figure 1. A photograph of the model is shown in figure 2. The dimensional characteristics of the airplane are presented in table I.

The model was ballasted 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 for the recovery attempts. Sufficient hinge moments were exerted on the controls for the recovery attempts to reverse them fully and rapidly.

In addition to ailerons, the lateral control system of the F9F-6 includes spoiler-type surfaces called flaperons. The flaperons are located on the upper surface of the wing near the trailing edge and are inboard of the ailerons. (See figs. 1 and 2.)

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that described in reference 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, the recovery attempt is made by moving one or more controls by means of the remote-control mechanism. After recovery, the model dives into a safety net. The spin data obtained from these tests are then converted to corresponding full-scale values by methods also described in reference 2.



Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of the model for the normal spinning-control configuration (elevator full up, lateral controls neutral, and rudder full with the spin) and for various other lateral-control—elevator combinations including neutral and maximum settings of the surfaces. Recovery is generally attempted by rapid reversal of the rudder from full with to full against the spin. Tests are also performed to evaluate the possible adverse effects on recovery of small deviations from the normal control configuration for spinning. For these tests, the elevator is set at either full up or two-thirds of its full-up deflection and the lateral controls are set at one-third of full deflection in the direction conducive to slower recoveries (against the spin, stick left in a right spin, for the F9F-6 model for all loadings). Recovery is attempted by rapidly reversing the rudder from full with the spin to only $2/3$ against the spin, by simultaneous reversal of rudder and elevator, or, for models within the mass range of the present model, by simultaneous rudder reversal to $2/3$ against the spin and stick movement to $2/3$ with the spin (for the present model the lateral controls were not moved but were set to $2/3$ with the spin). This control configuration and manipulation is referred to as the "criterion spin."

Turns for recovery are measured from the time the controls are moved, or the parachute is opened, to the time the spin rotation ceases. The criterion for a satisfactory recovery from a spin for the model has been adopted as $2\frac{1}{4}$ turns or less. Recovery characteristics of the model may be considered satisfactory if recovery attempted from the criterion spin in the manner previously described is accomplished within $2\frac{1}{4}$ turns.

For the spins which had a rate of descent in excess of that which can readily be obtained in the tunnel, the rate of descent was recorded as greater than the velocity at the time the model hit the safety net; for example, >300 feet per second, full scale. For these tests, the recovery was attempted before the model reached its final steeper attitude and while the model was still descending in the tunnel. Such results are considered conservative; that is, recoveries will not be as fast as when the model is in the final steeper attitude. For recovery attempts in which the model struck the safety net while it was still in a spin, the recovery was recorded as greater than the number of turns from the time the controls were moved to the time the model struck the safety net, as >3 . A >3 -turn recovery, however, does not necessarily indicate an improvement over a >7 -turn recovery. When the model recovered without control movement (rudder with the spin), the results were recorded as "no spin."



For the spin-recovery parachute tests, the minimum-size tail parachute required to effect recovery within $2\frac{1}{4}$ turns from the spin was considered satisfactory. For the tests the elevator was held full up and the lateral controls were full against the spin. The parachute was opened for the recovery attempts by actuating the remote-control mechanism and the rudder was held with the spin so that recovery was due entirely to the parachute action alone. Tests were made with the towline attached above and below the jet exhaust and also with the towline attached to the vertical tail just above the horizontal stabilizer near the trailing edge of the fin. The folded spin-recovery parachute was placed on the model in such a position that it did not influence the established spin. For the model tests, a rubber band holding the packed parachute to the model was released and the parachute was blown free of the model when the parachute towline was attached above or below the jet exhaust or the parachute was positively ejected into the air stream by means of a small spring. On the full-scale parachute installation it would be desirable to mount the parachute pack within the airplane structure, if possible, and it is recommended that a mechanism be employed for positive ejection of the parachute.

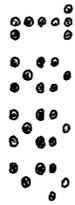
PRECISION

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

α , deg	± 1
ϕ , deg	± 1
V, percent	± 5
Ω , percent	± 2
Turns for recovery -	
When obtained from motion-picture records	$\pm \frac{1}{4}$
When obtained by visual estimates	$\pm \frac{1}{2}$

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

Comparison between model and full-scale results in reference 3 indicated that model tests satisfactorily predicted full-scale recovery characteristics approximately 90 percent of the time and that for the remaining 10 percent of the time, the model results were of value in predicting some of the details of the full-scale spins. The airplanes



generally spun at an angle of attack closer to 45° than did the corresponding models. The comparison presented in reference 3 also indicated that generally the airplanes spun with the inner wing tilted more downward and with a greater altitude loss per revolution than did the corresponding models.

Because it is impracticable to ballast the model exactly and because of inadvertent damage to the model during tests, the measured weight and mass distribution of the F9F-6 model varied from the true scaled-down values within the following limits:

Weight, percent	0 to 1 high
Center-of-gravity location, percent \bar{c}	0 to 1 forward
Moments of inertia:	
I_x , percent	3 to 4 high
I_y , percent	1 to 4 high
I_z , percent	1 to 2 low

The accuracy of measuring the weight and mass distribution of the model 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 $\pm 1^\circ$.

Test Conditions

The loadings possible on the airplane and those investigated on the model are indicated in table II. For all tests, the landing gear and flaps were retracted and the canopy was closed.

The mass-distribution parameters for the various airplane and model loadings are plotted in figure 3. As is discussed in reference 4, figure 3 may be used as an aid in predicting the relative effectiveness of the controls on the recovery characteristics of the model.

The normal maximum control deflections used in the tests (measured perpendicular to the hinge lines) were:

Rudder, deg	25 right, 25 left
Elevator, deg	30 up, 15 down
Ailerons, deg	15 up, 15 down
Flaperons, deg	55 up

As has been stated previously, the flaperons are upper-surface spoilers and are used in conjunction with the ailerons for lateral control. The flaperons deflect linearly with stick deflection (right flaperon deflects when stick is moved laterally right) and are fully deflected after 75 percent of the lateral stick travel.

RESULTS AND DISCUSSION

The results of the model spin tests are presented in charts 1 and 2 and in table III. Inasmuch as the results to the right and left were similar, the data are arbitrarily presented in terms of right spins.

Erect Spins

Normal flight loading.- Chart 1 presents the results of tests for the normal flight loading (loading point 1 in table II and fig. 3). The results indicate that for up settings of the elevator with the stick laterally neutral or against the spin, (stick left in a right spin) two conditions were indicated as being possible: Either the model motion was so oscillatory that the model would not spin or spins of an oscillatory nature generally persisted, the oscillations being primarily in roll and yaw. In some instances the oscillations damped and the model spun smoothly for varying periods of time. Unsatisfactory recoveries were frequently obtained for the preceding control configurations whether the rudder was reversed during the oscillatory or the smooth phase of the spin. Although not presented on the charts, results of brief tests indicated that, for the criterion-spin control configuration and for the stick full against spins, movement of the elevator down in conjunction with rudder reversal did not have any beneficial effect on recoveries. When the lateral controls were placed to simulate stick full with the spin, however, steep spins were obtained and recoveries by rudder reversal alone were consistently rapid. The model test results also showed that with the lateral controls set to 2/3 with the spin satisfactory recoveries were obtained even though the rudder was reversed to only 2/3 against the spin. On the basis of these results, it appears that recoveries from spins on the full-scale airplane will be satisfactory if rudder reversal is accompanied by movement of the ailerons and flaperons (lateral controls) to full with the spin. It is recommended that this recovery technique be employed. The results of this investigation are consistent with the information presented in reference 5 which indicates that for airplanes having the geometric and mass characteristics of the F9F-6, provision of a rolling moment in the direction of the spin is effective in the termination of spins. Although not specifically investigated on this

model, on the basis of past spin-tunnel experience it appears that the ailerons are the predominant controls in providing a rolling moment at spinning attitudes for the F9F-6 model and that the flaperons are relatively ineffective.

Effect of loading variation.- Results of brief tests (not presented in chart form) and spin-tunnel experience indicate that the spin and recovery characteristics of the F9F-6 for the range of airplane loadings indicated in table II will not vary appreciably from the results presented herein for the normal loading. Brief test results also indicate that moving the center of gravity forward 4 percent or rearward 7 percent of the mean aerodynamic chord from normal will have little effect on the spin-recovery characteristics of the airplane.

Inverted Spins

The results of the inverted-spin tests of the model in the normal flight loading are presented in chart 2. The order used for presenting the data for the inverted spins is different from that used for erect spins. For inverted spins, controls crossed for the established spin (right rudder pedal forward and stick to the left of the pilot for a spin to the right of the pilot) is presented to the right of the chart and stick back is presented at the bottom. When the controls are crossed in the established spin, the lateral controls aid the rolling motion; when the controls are together, the lateral controls oppose the rolling motion. The angle ϕ and the elevator position in the chart are given as up or down relative to the ground.

Results of model inverted-spin tests indicate that recoveries will be satisfactory for any inverted spins obtained on the airplane by full rapid rudder reversal.

Spin-Recovery Parachutes

The results of tests performed with spin-recovery parachutes attached to the tail of the model are presented in table III. Normally the criterion spin is used for parachute-recovery tests, but the lateral-control-full-against-elevator-full-up spin was used for this investigation because the model was somewhat easier to control in the tunnel for this control configuration. Inasmuch as the model spin characteristics were essentially the same for the elevator full-up-lateral-control-full-against spin and for the criterion spin, however, the results obtained are considered applicable for the criterion spin also. The results presented in table III show that a tail parachute 11.4 feet in diameter (measured laid out flat) with a towline length equivalent to approximately the semispan (18 ft) should satisfactorily terminate spins



on the full-scale F9F-6 airplane by parachute action alone. The model test results indicated that the parachute towline should be attached above the horizontal tail near the trailing edge of the fin to prevent the parachute from fouling on the horizontal tail. Frequent fouling of the parachute occurred when the towline was attached below the horizontal tail on the model. The drag coefficient of the 11.4-foot parachute (full-scale value) was approximately 0.73 based on the area of the parachute when it is laid out flat. If a parachute with a different drag coefficient is used, a corresponding adjustment will be required in parachute size. Reference 6 indicates that conventional flat-type parachutes made of low-porosity materials are unstable and may seriously affect the stability of the airplane if the parachute is opened in normal flight to test its operation. It may be desirable, therefore, to use a stable parachute (ref. 6) as an emergency spin-recovery device on the full-scale airplane.

Landing Condition

The landing condition was not investigated on this model inasmuch as current Navy specifications require this airplane to be spin-demonstrated in the landing condition from only a 1-turn spin, an incipient spin, whereas spin-tunnel-test data are obtained for the fully developed spin.

An analysis of model tests to determine the effect of landing gear and flaps (ref. 7) indicates that although the F9F-6 will probably recover satisfactorily from an incipient spin in the landing condition, recoveries from fully developed spins will probably be unsatisfactory. If a spin is inadvertently entered in the landing condition, the flaps and landing gear should be retracted and recovery attempted immediately.

Recommended Recovery Technique and Control Forces

Based on the results obtained with the model, the following recovery technique is recommended for all loadings and conditions of the airplane:

For erect spins, the ailerons and flaperons (lateral controls) should be moved to full with the spin (stick full right in a right spin) simultaneously with rudder reversal to full against the spin, and approximately 1/2 turn later the stick should be moved forward.

For recovery from inverted spins, the rudder should be reversed briskly to full against the spin.

Results of approximate computations based on hinge-moment data for an unbalanced rudder presented in reference 8 indicate that the force required to maintain the rudder full against the spin may vary from high to low forces (because of the oscillatory motion of the airplane) but that the forces will probably be within the capabilities of the pilot. No attempt was made to estimate the forces required to maintain the lateral controls full with the spin because of the lack of applicable hinge-moment data. To assure satisfactory recoveries from erect spins of this airplane, provision should be made to insure full movement of the lateral controls to full with the spin.

CONCLUSIONS

Based on the results of tests of a $\frac{1}{24}$ -scale model of the Grumman F9F-6 airplane, the following conclusions regarding the spin and recovery characteristics of the airplane at an altitude of 15,000 feet are made:

1. The erect spins obtained on the airplane in the normal loading and clean condition will be oscillatory primarily in roll and yaw and the oscillations may become so violent that the airplane will oscillate out of the spin without movement of the controls. The oscillatory spin may persist, however, and to insure satisfactory recoveries from this spin the following recovery technique should be used: Brisk rudder reversal and simultaneous movement of the ailerons and flaperons (lateral controls) to full with the spin (stick right in a right spin) followed approximately 1/2 turn later by forward movement of the stick.
2. Variations in loading within the range indicated possible on the airplane, or small forward or rearward movements of the center of gravity will have little appreciable effect on the spin or spin-recovery characteristics.
3. An 11.4-foot diameter (laid out flat) tail parachute having a drag coefficient of 0.73 (based on laid-out-flat area) and having a towline length equivalent to approximately the semispan will be effective for emergency recovery from demonstration spins. The parachute towline should be attached above the horizontal tail to prevent the parachute from fouling and the parachute should be positively ejected.
4. Satisfactory recoveries from inverted spins will be obtained by full reversal of the rudder.



5. If a spin is inadvertently entered in the landing condition, the flaps and landing gear should be retracted and recovery should be attempted immediately.

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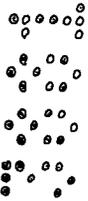


TABLE I.- DIMENSIONAL CHARACTERISTICS OF
GRUMMAN F9F-6 AIRPLANE

Over-all length, ft	41.02
Wing:	
Span, ft	34.50
Area, sq ft	300
Incidence, deg	0
Dihedral, deg	0
Aspect ratio	4
Taper ratio	0.5
Leading edge \bar{c} behind leading edge of wing at the root, ft . .	6.01
\bar{c} , ft	8.94
Sweepback at 25 percent chord, deg	35
Airfoil section	64A010
Ailerons:	
Span, ft, each (parallel to Y-axis)	3.66
Horizontal tail:	
Span, ft	10.84
Total area, sq ft	41.17
Sweepback at 25 percent chord, deg	35
Tail-damping ratio	0.0421
Unshielded rudder volume coefficient	0.0112
Tail-damping-power factor	0.000472
Side area moment factor (for normal center of gravity)	0.478

12.10
7.5
12.5



TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADINGS POSSIBLE ON THE GRUMMAN F9F-6 AIRPLANE
AND FOR LOADINGS TESTED ON THE $\frac{1}{24}$ -SCALE MODEL

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

No.	Loading	Weight (lb)	Center-of-gravity location		Relative density, μ		Moments of inertia (Slug-feet ²)			Mass parameters		
			x/\bar{c}	z/\bar{c}	Sea level	15,000 feet	I_x	I_y	I_z	$\frac{I_x - I_y}{mb^2}$	$\frac{I_y - I_z}{mb^2}$	$\frac{I_z - I_x}{mb^2}$
Loadings possible on airplane												
1	Normal flight	15,600	0.243	-0.032	19.68	31.29	9,148	26,676	33,943	-304×10^{-4}	-126×10^{-4}	430×10^{-4}
2	Flight most forward center of gravity	15,600	0.230	-0.031	19.69	31.29	9,257	26,834	33,994	-305	-124	429
3	Center of gravity moved rearward and I_x increased approximately 45 percent	15,600	0.300	-0.027	19.68	31.29	13,354	25,981	37,363	-219	-197	416
4	Take-off	17,900	0.254	-0.040	22.59	35.90	13,488	27,280	38,708	-208	-173	381
Average model values												
1	Normal flight	15,580	0.237	-0.052	19.66	31.25	9,546	26,757	33,529	-299×10^{-4}	-118×10^{-4}	417×10^{-4}
3	Center of gravity moved rearward and I_x increased approximately 45 percent	15,556	0.310	-0.039	19.63	31.20	13,574	27,590	37,336	-244	-169	413
5	Center of gravity moved 4 percent \bar{c} forward	15,556	0.202	-0.060	19.63	31.20	9,652	31,042	36,964	-372	-103	475
6	Center of gravity moved 7 percent \bar{c} rearward	15,556	0.310	-0.039	19.63	31.20	9,979	27,590	33,738	-306	-107	413

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TABLE III.- SPIN-RECOVERY TAIL PARACHUTE DATA OBTAINED WITH
THE $\frac{1}{24}$ -SCALE MODEL OF THE GRUMMAN F9F-6 AIRPLANE

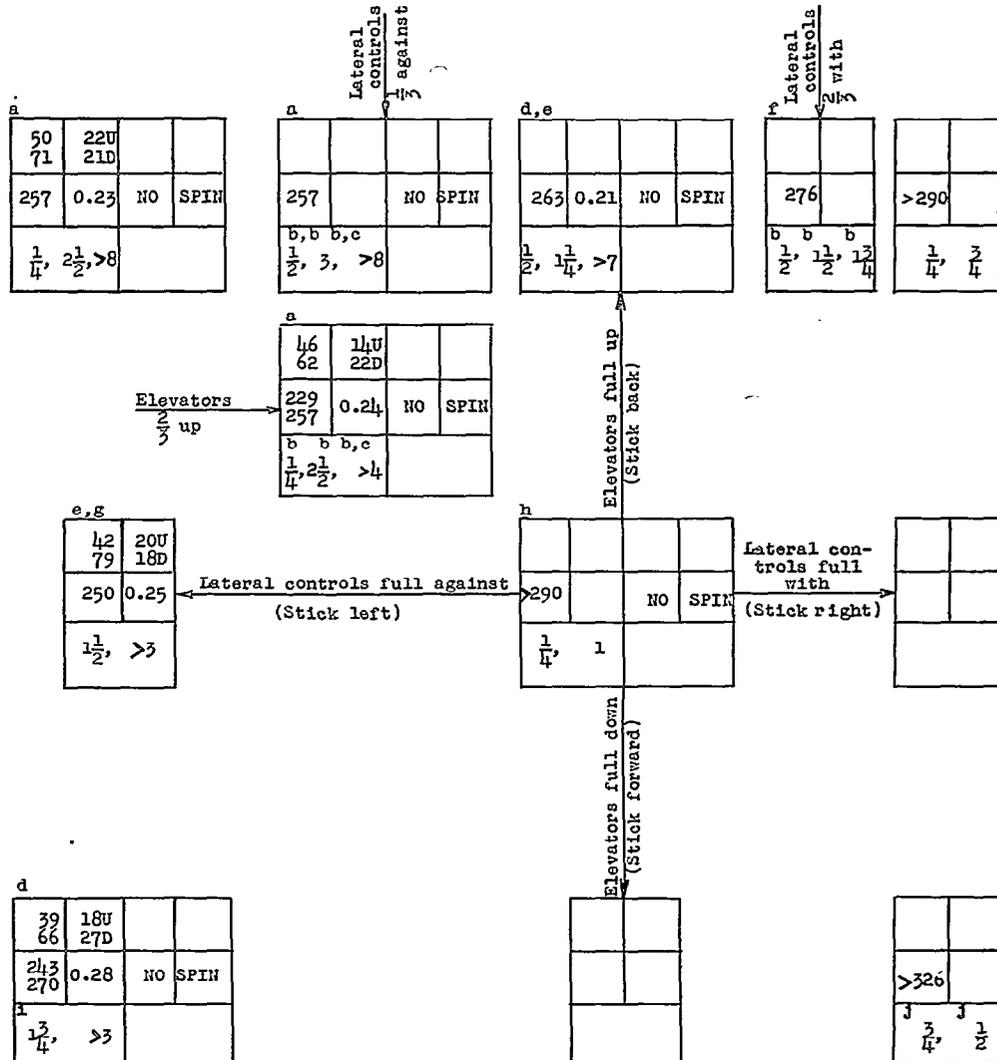
[Normal flight loading (loading point 1 in table II and fig. 3); recovery attempted by opening tail parachute; towline attached to fin above horizontal tail; right erect spins; control setting for spin - elevators full up, lateral controls full against, rudder full with spin; model values have been converted to corresponding full-scale values]

Parachute diameter (ft)	Towline length (ft)	Approximate parachute drag coefficient	Turns for recovery
7.4	18.0	0.78	$\frac{1}{4}$, $1\frac{1}{2}$, >2, $2\frac{1}{2}$, $>2\frac{3}{4}$
8.4	18.0	.68	$\frac{3}{4}$, $>1\frac{1}{2}$, >3, $>3\frac{1}{2}$, >5
9.6	18.0	.76	1, >2, 3, $>4\frac{1}{2}$, >8
10.0	18.0	.68	$1\frac{1}{2}$, >2, >3, $3\frac{1}{4}$, >10
11.4	18.0	.73	$\frac{1}{4}$, $\frac{1}{2}$, 1, $1\frac{1}{2}$, $1\frac{3}{4}$, 2



CHART 1.- ERECT SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL IN THE NORMAL FLIGHT LOADING

[Loading point 1 in table II and figure 3; recovery attempted by full rapid rudder reversal except as indicated (recovery attempted from, and steady-spin data presented for, rudder full with spins). right spins]



^aTwo conditions possible. Either model motion becomes so oscillatory that model oscillates out of spin or spinning motion persists. The spin is oscillatory primarily in roll and yaw but at times the model spins smoothly.

^bRecovery attempted by reversal of the rudder to only $\frac{2}{3}$ of its full deflection against the spin.

^cVisual estimate.

^dTwo conditions possible. Either model motion becomes so oscillatory that model oscillates out of spin or a spin oscillatory primarily in roll and yaw persists.

^eWandering spin.

^fWandering and whipping spin. At times model goes into a wide spiral.

^gOscillates primarily in roll and yaw.

^hTwo conditions possible, either model spins steeply or does not spin.

ⁱRecovered in an inverted dive.

^jRecovered in inverted spin.

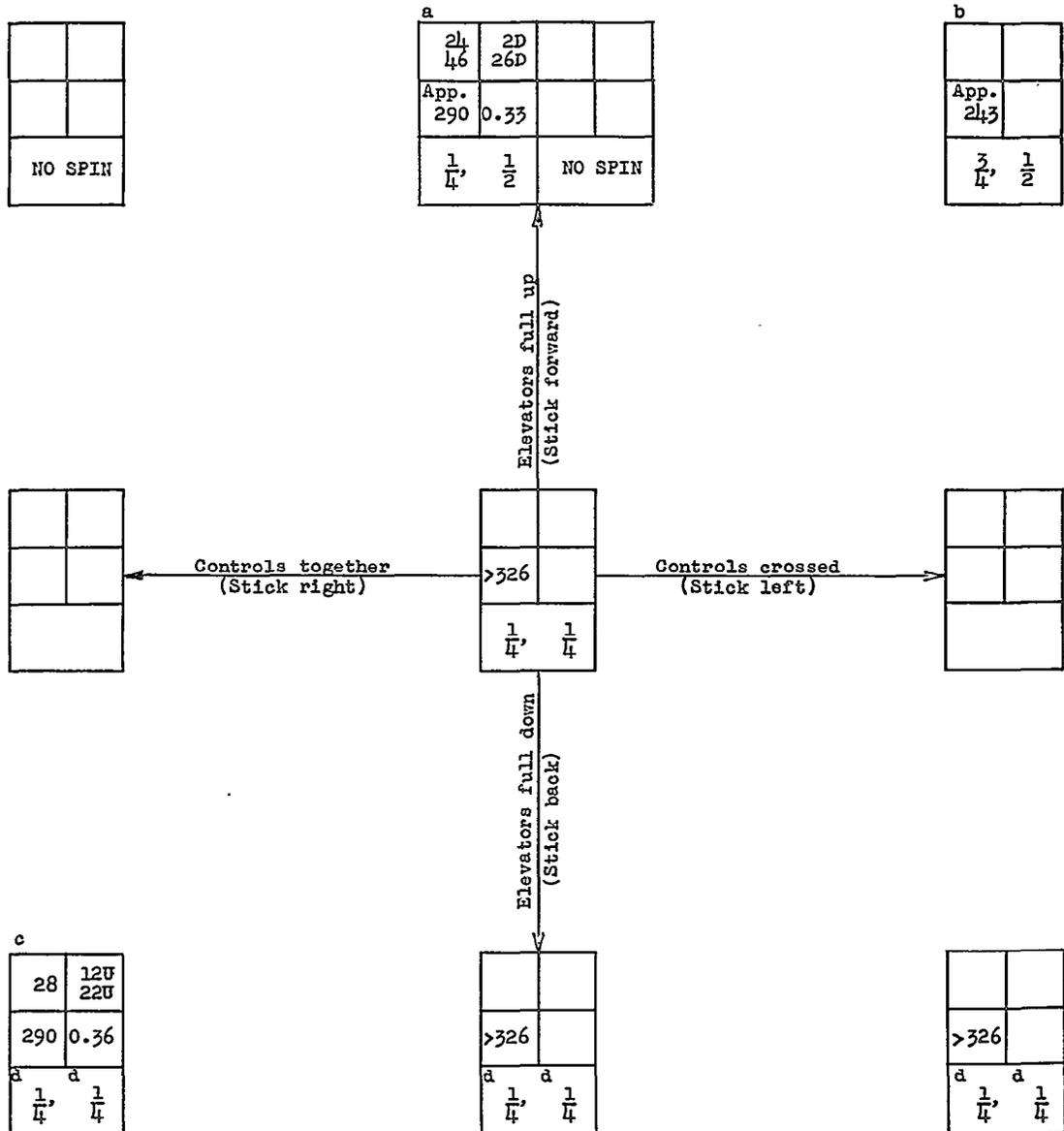
Model values converted to corresponding full-scale values.
 U inner wing up
 D inner wing down

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



CHART 2.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Loading point 1 in table II and figure 3; recovery attempted by full rapid rudder reversal (recovery attempted from, and steady-spin data presented for, rudder full with spins); spins to pilot's right]



^aTwo conditions possible. Range of values of oscillatory spin given.
^bWandering spin.
^cOscillatory spin, range of values given.
^dRecovers in an erect glide.

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

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





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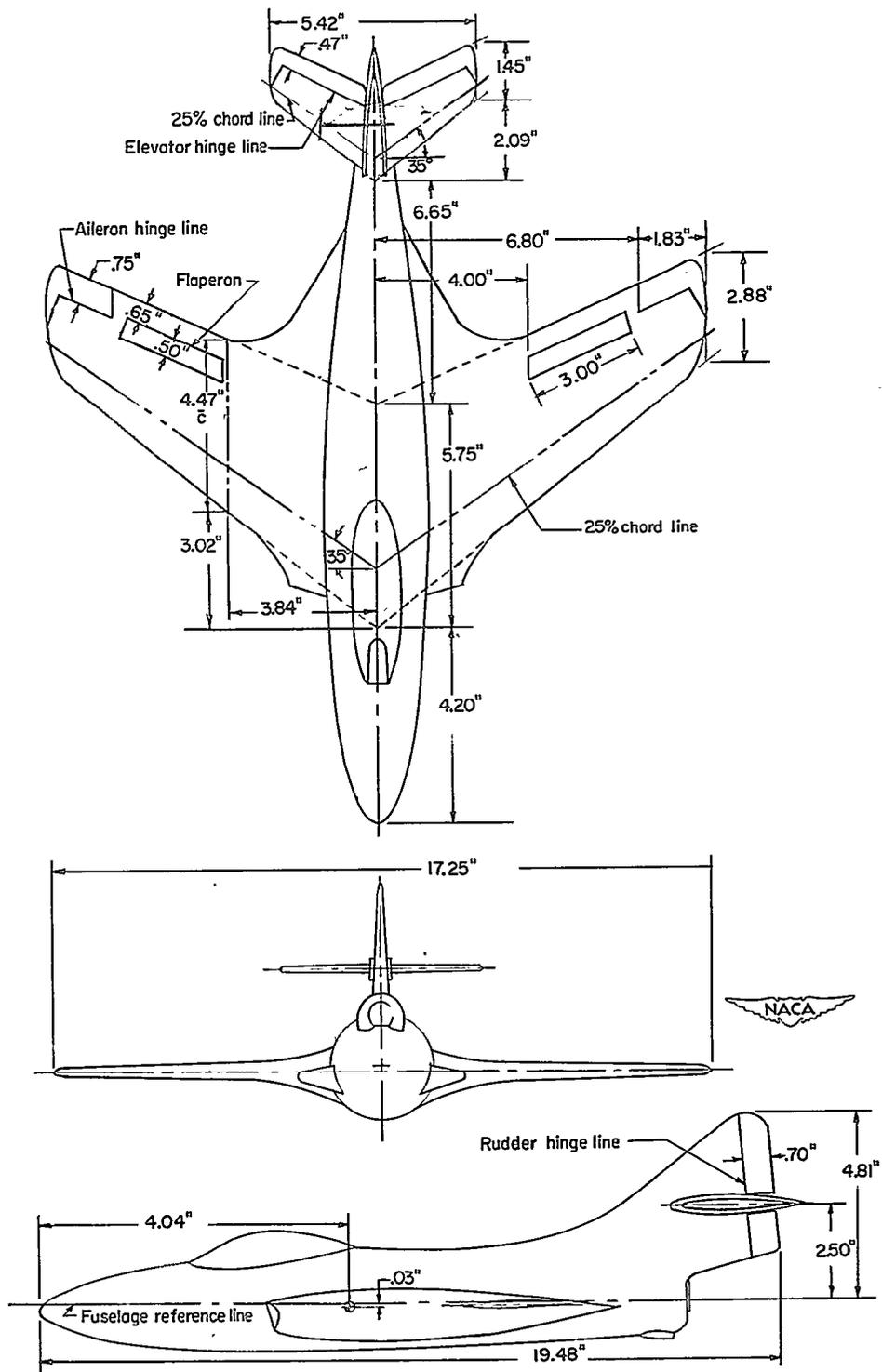
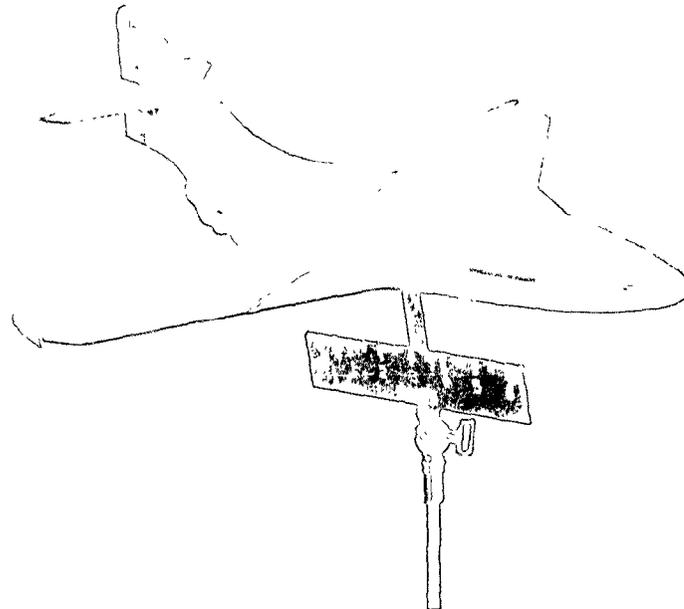


Figure 1.- Three-view drawing of the $\frac{1}{24}$ -scale model of the Grumman F9F-6 airplane. Center of gravity is shown for normal flight loading.

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Figure 2.- Photograph of model showing ailerons and flaperons deflected.

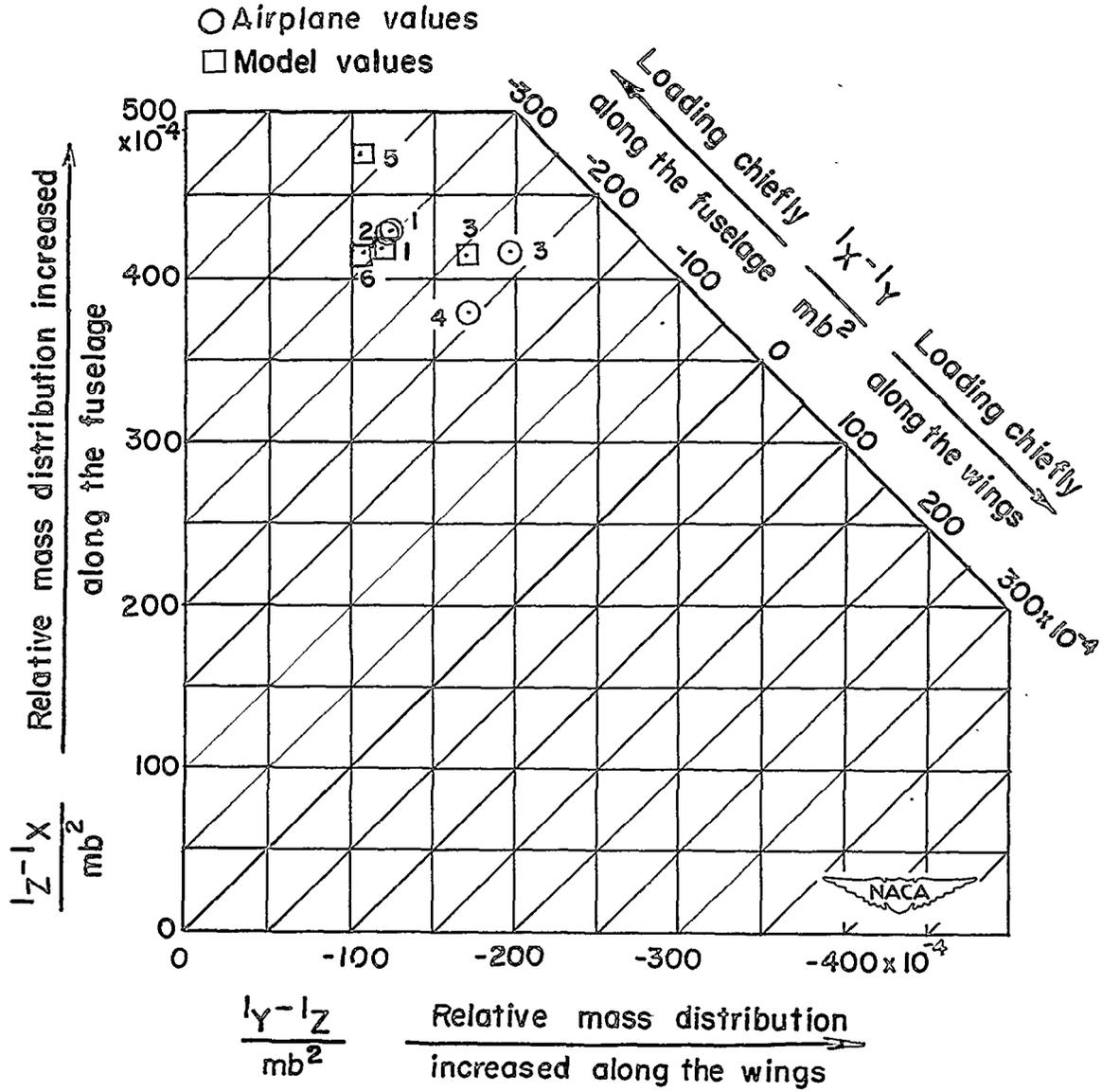


Figure 3.- Mass parameters for the loading conditions of the F9F-6 airplane and for loadings investigated on the model.

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