NACA

RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING-TUNNEL INVESTIGATION TO DETERMINE THE EFFECT OF SPIN-RECOVERY ROCKETS AND THRUST SIMULATION ON THE RECOVERY CHARACTERISTICS OF A 1/21-SCALE MODEL OF THE CHANCE VOUGHT F7U-3 AIRPLANE

TED NO. NACA AD 3103

By Sanger M. Burk, Jr., and Frederick M. Healy

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

An investigation of a 1/21-scale model of the Chance Vought F7U-3 airplane in the combat-loading condition has been conducted in the Langley 20-foot free-spinning tunnel. The recovery characteristics of the model were determined by use of spin-recovery rockets for the erect and inverted spinning condition. The rockets were so placed as to provide either a yawing or rolling moment about the model center of gravity. Also included in the investigation were tests to determine the effect of simulated engine thrust on the recovery characteristics of the model.

On the basis of model tests, recoveries from erect and inverted spins were satisfactory when a yawing moment of 22,200 foot-pounds (full scale) was provided against the spin by rockets attached to the wing tips; the antispin yawing moment was applied for approximately 9 seconds (full scale). Satisfactory recoveries were obtained from erect spins when a rolling moment of 22,200 foot-pounds (full scale) was provided with the spin (rolls right wing down in right spin). Although the inverted spin was satisfactorily terminated when a rolling moment of equal magnitude was provided, a roll rocket was not considered to be an optimum spin-recovery device to effect recoveries from inverted spins for this airplane because of resulting gyrations during spin recovery. Simulation of engine thrust had no apparent effect on the spin recovery characteristics.

INTRODUCTION

Military airplanes that are required to be spin demonstrated must be equipped with an emergency spin-recovery device in the event that the normal recovery technique (that is, by control movement) is not effective in producing a recovery. Interest has been evidenced recently in the use of rockets as an emergency spin-recovery device. The feasibility of using rockets for recovery from the spin is indicated from results of several investigations conducted in the Langley 20-foot free-spinning tunnel (refs. 1, 2, and unpublished data). Comparison made in reference 2 between model and full-scale spin recoveries obtained by use of rockets indicated excellent agreement between model and full-scale test results. Therefore, at the request of the Bureau of Aeronautics, Department of the Navy, rocket spin-recovery tests which also included tests simulating the effect of engine thrust on spin recovery were conducted on a 1/21-scale model of the Chance Vought F7U-3 airplane in the Langley 20-foot free-spinning tunnel.

The spin and recovery characteristics of this model by control manipulation have been determined in a previous investigation (ref. 3). In the present investigation the recovery characteristics of the model from erect and inverted spins were determined by the application of an antispin yawing moment about the Z body axis of the model produced by rockets mounted at the wing tips. In addition, tests were conducted on the model to determine the recovery characteristics when a rolling moment was applied about the X body axis by rockets mounted at the wing tips. Although, in the past, experience has indicated, in general, that the application of a moment is necessary for spin recovery, it was considered desirable to conduct additional tests on the model to determine what effect firing a rocket to simulate the application of a large thrust, such as is available from present turbojet engines, would have in effecting a spin recovery.

SYMBOLS

An illustration of an airplane in a spin is shown in figure 1; the positive directions of the forces and moments along and about the body axes are also indicated.

X longitudinal force acting along X body axis, positive forward, lb

Y lateral force acting along Y body axis, positive to right, lb

Z normal force acting along Z body axis, positive downward, lb

L	rolling moment acting about X body axis, positive when it tends to lower right wing, ft-lb
M	pitching moment acting about Y body axis, positive when it tends to increase angle of attack, ft-lb
N	yawing moment acting about Z body axis, positive when it tends to turn airplane to right, ft-lb
C_l	rolling-moment coefficient, L/qSb
C_n	yawing-moment coefficient, N/qSb
q	dynamic pressure, $\frac{\rho V^2}{2}$, lb/ft^2
S	wing area, sq ft
b	wing span, ft
Ω	angular velocity about spin axis, radians/sec
ρ	air density, slugs/cu ft
V	rate of descent, ft/sec
$\bar{c}$	mean aerodynamic chord, in.
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of perpendicular distance between center of gravity and thrust line to mean aerodynamic chord, positive when center of gravity is below thrust line
W	weight of airplane, lb
g	acceleration due to gravity, 32.2 ft/sec^2
m	mass of airplane, W/g, slugs
μ	airplane relative-density coefficient, $m/\rho Sb$
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, $slug\text{-}ft^2$

$\frac{I_X - I_Y}{mb^2}$ 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

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

ϕ angle of wing tilt (commonly called angle of bank; angle between span axis and horizontal), positive when right wing is down, deg

T thrust of rocket, oz unless otherwise indicated

t time, sec

APPARATUS AND METHODS

Model

The 1/21-scale model of the Chance Vought F7U-3 airplane used in the present investigation was already available since it had been used in a previous spin-tunnel investigation (ref. 3). The model was made primarily of balsa wood. A photograph of the model is shown as figure 2, a three-view drawing of the model is shown as figure 3, and a three-view drawing of the model as tested with the rockets installed at various locations is shown as figure 4. Comparison of figures 3 and 4 shows that a very small portion of the tail end of the fuselage had to be cut off in order to install a large tail rocket. The main rudders of the model are the large-span rudders mounted high on the vertical tails as shown in figures 2 and 3. Short-span auxiliary rudders are shown below the main rudders in figures 2 and 3. Characteristics of the airplane represented by the model are given in table I.

The longitudinal and lateral control of the airplane and model is obtained from deflection of one set of control surfaces called ailavators. For simplicity, ailavator deflections for longitudinal and lateral control will be referred to, hereinafter, as elevator deflection and aileron deflection, respectively. The maximum control deflections as given in table I are perpendicular to the hinge lines. These correspond to the deflections currently in use on the airplane and are somewhat different from those used in the previous investigation (ref. 3).

Model Rockets

The Langley Model Propulsion Section of the Pilotless Aircraft Research Division designed and developed the model rockets used in the present investigation. The rockets are precision built and made of steel. These rockets are the initial results of a systematic program to develop various sizes of rockets for use on dynamic spin-tunnel models. The only size rocket available at present delivering its specified thrust is a small rocket producing 3 ounces of thrust for 2 seconds. The magnitude and duration of the rocket thrust for several of these model rockets are shown in figure 5. It should be noted that the magnitude of the rocket thrust and the time of the rocket firings are fairly similar and thus indicate good repeatability of firings. This particular size rocket has been used satisfactorily in previous spin-tunnel investigations (for example, ref. 2). Based on the test altitude (15,000 feet) and scale of the model used in the present investigation, the thrust of this small rocket is equivalent to 1,094 pounds of thrust, full scale, and the corresponding full-scale thrust duration is about 9 seconds. A diagrammatic sketch of this rocket and the electrical circuit is shown in figure 6. A more detailed description of this rocket is given in reference 2.

At present a model rocket large enough to simulate the full-scale thrust of the engine and afterburner of the subject airplane in spinning attitudes is not available. However, in order to approximate the thrust of the airplane a large intermediate rocket was used. A photograph of this rocket mounted on the thrust-measuring apparatus is shown in figure 7. The magnitude and duration of the rocket thrust for two of the large intermediate rockets as shown in figure 8 indicate good repeatability of firings. The average value of the thrust appears to be about 10 ounces for about 5 seconds; based on the test altitude and scale of the model, this value corresponds to full-scale values of about 3,640 pounds for 23 seconds. Information received from Chance Vought Aircraft, Inc., indicates that the total thrust of the two engines of the airplane including afterburners that should have been simulated on the spin model was estimated to be 6,500 pounds at 15,000 feet, the altitude simulated for the present tests. (It should be noted that, although the combined static-thrust ratings of the two engines without afterburners indicated in table I is 12,000 pounds, the thrust is considerably less at spinning attitudes and altitudes.)

Wind-Tunnel and Testing Technique

The tests of the dynamic model were conducted in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that of the Langley 15-foot free-spinning tunnel which is described in reference 4 except that the technique in launching the model has been changed. With the controls set in the desired position, the model is now launched by hand with rotation into the vertically rising airstream. After a number of turns in the established spin, recovery is normally attempted by movement of one or more controls by means of a remote-control mechanism installed in the model. After recovery the model dives into a safety net. For the current investigation, the remote-control mechanism was used only to activate the rockets.

For the rocket spin-recovery tests, the controls on the model were set in such a manner as to be very conducive to maintaining the spin since an emergency spin-recovery device must effect a recovery regardless of the position of the controls. In order to attempt a spin recovery, the rockets were fired while the controls remained fixed; thus, the recovery was due entirely to the action of the rockets. Each test generally was made at least twice as a check on the results. The turns for recovery were measured from the time the rocket was fired to the time the spin rotation ceased. Recovery characteristics of the model were considered satisfactory if recovery from the spin occurred in $2\frac{1}{4}$ turns or less. This criterion was used on the basis of a correlation of available full-scale airplane spin-recovery data and corresponding model test results. The results of the present investigation have been converted to corresponding full-scale values by methods described in reference 4. When the moments produced by the rockets were converted to coefficient form, the density at the spin-test altitude and the rate of descent of the model in the steady-spin condition were used.

TEST CONDITIONS

As a result of installing rockets on the model, it was not possible to ballast the model so as to obtain the exact scaled-down individual moments of inertia of the airplane without rockets at the desired simulated test altitude of 15,000 feet ($\rho = 0.001496$ slug/cu ft); however, it was possible to make the moment-of-inertia differences of the model approximately the same as the scaled-down moment-of-inertia differences of the airplane. Brief tests were made in order to determine whether the differences between model and airplane (scaled-down) individual moments of inertias, the addition of the rockets, and the changes in control deflections would appreciably affect the spinning characteristics of the model from those presented in reference 3. The mass characteristics and inertia parameters for the combat-loading condition of the airplane and the corresponding loading condition investigated on the model are shown in table II. All tests were conducted with the model in the clean condition (cockpit closed, flaps neutral, and landing gear retracted). The control settings used for the erect spinning condition of the model were as follows: main rudders full with the spin, auxiliary rudders full with the spin, ailerons one-third against the spin (stick left in a right spin), and elevator two-thirds up. For the inverted spins to the pilot's right, the following control configuration was chosen: main rudders full with the spin (right pedal forward for a spin to pilot's right), auxiliary rudders full with the spin, ailerons full against the spin or controls together (stick full right in an inverted spin to pilot's right), and elevator full down with respect to the ground (stick full back). (When the controls are together in the developed inverted spin, the ailerons oppose the rolling motion.)

Yaw Rockets

For the erect and inverted-spin conditions where an antispin yawing moment was applied to the model, the small rockets (3 ounces for 2 seconds) were mounted on the wing tips so that the thrust of the rockets was perpendicular to the Z body axis of the model and thus applied a yawing moment about this axis. Only the rocket on the outboard wing tip (right wing tip for left spin) was fired, thrust rearward; this condition applied an antispin yawing moment equal to 22,200 foot-pounds, full scale ($C_n = 0.021$).

Roll Rockets

A rolling moment was applied about the X body axis of the model for both the erect and inverted-spin conditions by mounting the small rockets at the wing tips with the rocket thrust perpendicular to the wing-chord plane. Only the roll rocket on the outboard wing tip was fired, thrust up; thus, a pro-spin rolling moment equal to 22,200 foot-pounds, full scale (rolling-moment coefficient = 0.021) was provided.

Thrust Simulation Rockets

Although the full-scale airplane has two jet engines mounted side by side in the fuselage with separate exhausts, it was decided because of practical considerations to simulate the engine thrust with a single large intermediate rocket. Although two large rockets would have more closely approximated the total engine thrust, mass and space limitations restricted the installation to one rocket. Therefore, a large intermediate model rocket which provided a thrust equal to 3,640 pounds for 23 seconds (full-scale values) was mounted in the tail of the model with the line of thrust passing through the model center of gravity. Tests simulating the engine thrust were conducted on the model only in the erect spinning condition.

PRECISION

Model

The spin-tunnel results presented herein are believed to be the true values for 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 . . . . ±1/4
When obtained by visual estimate . . . . ±1/2

Comparison between model and full-scale results in reference 5 indicated that model tests satisfactorily predicted full-scale recovery characteristics by rudder reversal 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 5 also indicated that generally the airplane spun with the inner wing tilted more downward and with a greater altitude loss per revolution than did the corresponding model, although the higher rate of descent was found to be generally associated with the smaller angle of attack regardless of whether it was for the model or the airplane.

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 model varied from the original model values by the following amounts:

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

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 ±1°.

RESULTS AND DISCUSSION

The results for right and left spins were fairly similar; the film strips of the model motion (figs. 9 to 12) arbitrarily show the model spinning to the left. The model data are presented in terms of the full-scale values for the corresponding airplane. The results of the previous investigation (ref. 3) indicated that for the control settings similar to those used herein for the erect condition the model spun in an oscillatory manner at a rather flat attitude. For the inverted-spin condition with the control settings similar to those used for the present investigation, the results presented in reference 3 indicated the model spun steadily in a rather flat attitude. Results of brief tests made to determine whether changes made to the model for the present investigation (incurred primarily by the rocket installations) would appreciably affect its spinning characteristics indicated that the spin characteristics of the model were generally similar to those obtained previously (ref. 3) except that the erect spin was now slightly steeper. It thus appears that the spinning characteristics of the model were not affected appreciably by the changes made on the model.

Yaw Rockets

Erect spins.- Model results for the erect spins showed that, when the rocket on the outboard wing tip was fired so that an antispin yawing moment of 22,200 foot-pounds (full scale) or a C_n of 0.021 was provided, rapid recoveries ranging from 1/4 to 3/4 turns were obtained. The transition from the erect spinning condition to the recovery dive generally was smooth in that after the rocket was fired the rotation of the model decreased and simultaneously the model pitched down to a lower angle of attack. Sometimes the model began turning slightly in the other direction after termination of the spin rotation, probably because of both aileron setting and rocket thrust. A film strip illustrating this motion for a left spin after a rocket was fired on the right wing tip of the model is shown in figure 9.

Care should be taken in determining the size of rockets for emergency spin recovery since a rocket that is too large may be just as bad for recovery as one that is too small. If the thrust of a yaw rocket is too large, it is possible that the airplane will stop spinning in the original direction with no appreciable change in pitch attitude and commence spinning in the opposite direction. This conclusion is based on a result reported in reference 2 where a full-scale airplane recovered from a spin by use of yaw rockets and then entered a spin in the opposite direction because of excess rocket thrust. In addition, rocket spin-recovery tests conducted in the Langley 20-foot free-spinning tunnel on a model of a fighter-type airplane (unpublished) indicated the same results. Therefore, it appears desirable to have some means whereby the rocket thrust may be terminated or dumped at the will of the pilot.

Inverted spins.- Rocket spin-recovery tests performed while the model was spinning in an inverted attitude showed that satisfactory recoveries ranging from 3/4 to $1\frac{1}{2}$ turns were obtained when the wing-tip rocket was fired. The transition from the developed spin to the recovery was smooth in that as the rate of rotation slowed down the model pitched to a steep attitude. After pitching to a near vertical attitude the model rolled in the direction of the aileron setting. A film strip depicting a recovery from an inverted spin to the pilot's left after a yaw rocket was fired is shown in figure 10.

Roll Rockets

The relative effectiveness of airplane controls in producing a spin recovery is discussed in reference 6. It was indicated in this reference that deflecting the ailerons with the spin so as to provide a rolling moment in the direction of the spin (a pro-spin rolling moment) would aid recoveries if the value of the inertia yawing-moment parameter $\frac{I_X - I_Y}{mb^2}$ was larger than -50×10^{-4}. Thus, although the aileron effectiveness is considerably reduced at the high angles of attack encountered in spinning attitudes, it is still sufficient to affect the recovery characteristics of an airplane and it oftentimes enables recovery by aileron movement alone. On this basis it was decided to apply a relatively large rolling moment by use of rockets to the model used in the present investigation. Because the value of the inertia yawing-moment parameter of the model was greater than -50×10^{-4}, a pro-spin rolling moment was applied.

Erect spins.- When the roll rocket on the wing tip was fired for the erect spin condition (C_l equivalent to 0.021), satisfactory recoveries ranging from 1 to $1\frac{1}{2}$ turns were obtained. The transition from the erect spin to the recovery dive was fairly smooth in that after the rocket was fired the model rolled into the spin (remaining erect at all times) and simultaneously pitched down to a low angle of attack. The ensuing motion after recovery from the spin was a roll in the direction of the aileron setting even though the moment being applied by the rocket was in the opposite direction. A film strip showing the model recovering from a left spin by firing a roll rocket is presented in figure 11.

Inverted spins.- As a result of firing the roll rocket on the wing tip for the inverted-spin condition (C_l of 0.021), a rolling moment was produced which rolled the model almost 90° while it simultaneously pitched down somewhat. However, it continued to rotate about the vertical spin axis for about $1\frac{1}{4}$ turns and then commenced rolling in the direction in which the rolling moment was being applied by the ailerons but opposite to the direction of the moment being applied by the rocket. As the model rolled it pitched to an erect attitude because of the elevator setting and then continued rolling opposite to the direction of the original spin. The recovery was considered to have been completed when the model pitched erect. The recovery was considered to be satisfactory since the model recovered in $1\frac{3}{4}$ turns. Other rocket firings gave somewhat similar results. A film strip illustrating this motion is shown in figure 12. Although the roll rocket was effective in terminating the inverted spin, it was not considered to be an optimum spin-recovery device for effecting recoveries from inverted spins for this airplane because of the resulting gyrations of the model during the spin recovery.

Thrust Simulation Rockets

Inasmuch as very few tests have been performed in the past to determine the effect of engine thrust on the spin-recovery characteristics of airplanes, only a few results are available. In the present investigation only the thrust of the engine and afterburner was simulated; the gyroscopic effects produced by the rotating parts of the engine were not simulated because of practical considerations. Unpublished data, however, indicate that the gyroscopic effects of some jet engines may be large enough to retard or aid spin recoveries depending on the direction of the spin.

With the model spinning in the erect condition, the large rocket in the tail was fired. The thrust had no apparent effect on the spinning characteristics of the model. Although these results were not considered to be conclusive since the scaled-up model thrust was considerably less than desired (3,640 pounds applied against 6,500 pounds desired, full scale), the results can be considered as a first approximation as to what might be expected for this particular airplane.

CONCLUSIONS

Based on the results of rocket spin-recovery tests and tests simulating the effect of engine thrust on the spin recovery of a 1/21-scale model of the Chance Vought F7U-3 airplane in the clean condition at an equivalent altitude of 15,000 feet, the following conclusions are made:

1. Recoveries from erect and inverted spins were satisfactory when a yawing moment of 22,200 foot-pounds, full-scale (yawing-moment coefficient of 0.021) was provided against the spin by rockets attached to the wing tips; the rocket-thrust duration used was equivalent to 9 seconds, full-scale.

2. Satisfactory recoveries were obtained from erect spins when a rolling moment of 22,200 foot-pounds, full-scale (rolling-moment coefficient of 0.021) was provided with the spin (rolls right wing down in right spin) for about 9 seconds, full-scale. Although the inverted spin was satisfactorily terminated when a rolling moment of equal magnitude was applied, a roll rocket was not considered to be an optimum spin-recovery device to effect recoveries from inverted spins for this airplane because of resulting gyrations during spin recovery.

3. Simulation of engine thrust had no apparent effect on the spinning characteristics.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 27, 1954.

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TABLE I.- DIMENSIONAL CHARACTERISTICS, MAXIMUM CONTROL DEFLECTIONS,

AND POWER PLANT OF THE CHANCE VOUGHT F7U-3 AIRPLANE

Overall length, ft	43.79
Wing:	
Span, ft	39.72
Area, sq ft	535.3
Aspect ratio	2.94
Root chord, in.	194.06
Tip chord, in.	128.57
Mean geometric chord, in.	164.22
Leading edge mean aerodynamic chord rearward leading-edge root chord, in.	86.51
Taper ratio	0.66
Incidence (constant)	0
Dihedral, deg	0
Sweepback of quarter-chord line, deg	35
Airfoil section	CVA 4-(00)-(12)-(40)-(1.1)-(1.0)
Ailavator:	
Span, b/2, percent	47.2
Total area, sq ft	74.36
Chord, percent $\bar{c}$	28.1
Vertical tail:	
Total area, sq ft	156.3
Rudder area, aft hinge line, sq ft	12.9
Auxiliary rudders, sq ft	11.9
Aspect ratio	1.45
Sweepback of quarter-chord line, deg	45
Airfoil section	NACA 64_1-008.9 (modified)
Power plant:	
Engine designation	Westinghouse J-46-WE-8 (afterburner)
Total static thrust for two engines (excluding afterburners), lb	12,000
Normal maximum control deflections:	
Main rudders, deg	±28.3
Auxiliary rudders, deg	±21.8
Ailavators as ailerons, deg	±16.5
Ailavator as elevator, deg	32.4 up, 11 down

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE CHANCE VOUGHT F7U-3 AIRPLANE AND FOR THE LOADING TESTED ON THE 1/21-SCALE MODEL

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

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 ft	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											
Combat, landing gear retracted	24,656	0.126	-0.0104	15.14	24.07	24,097	45,161	67,228	-174×10^{-4}	-183×10^{-4}	357×10^{-4}
Model values converted to full scale											
Combat, landing gear retracted	24,499	0.123	-0.024	15.05	23.92	31,315	52,066	80,688	-173×10^{-4}	-238×10^{-4}	411×10^{-4}

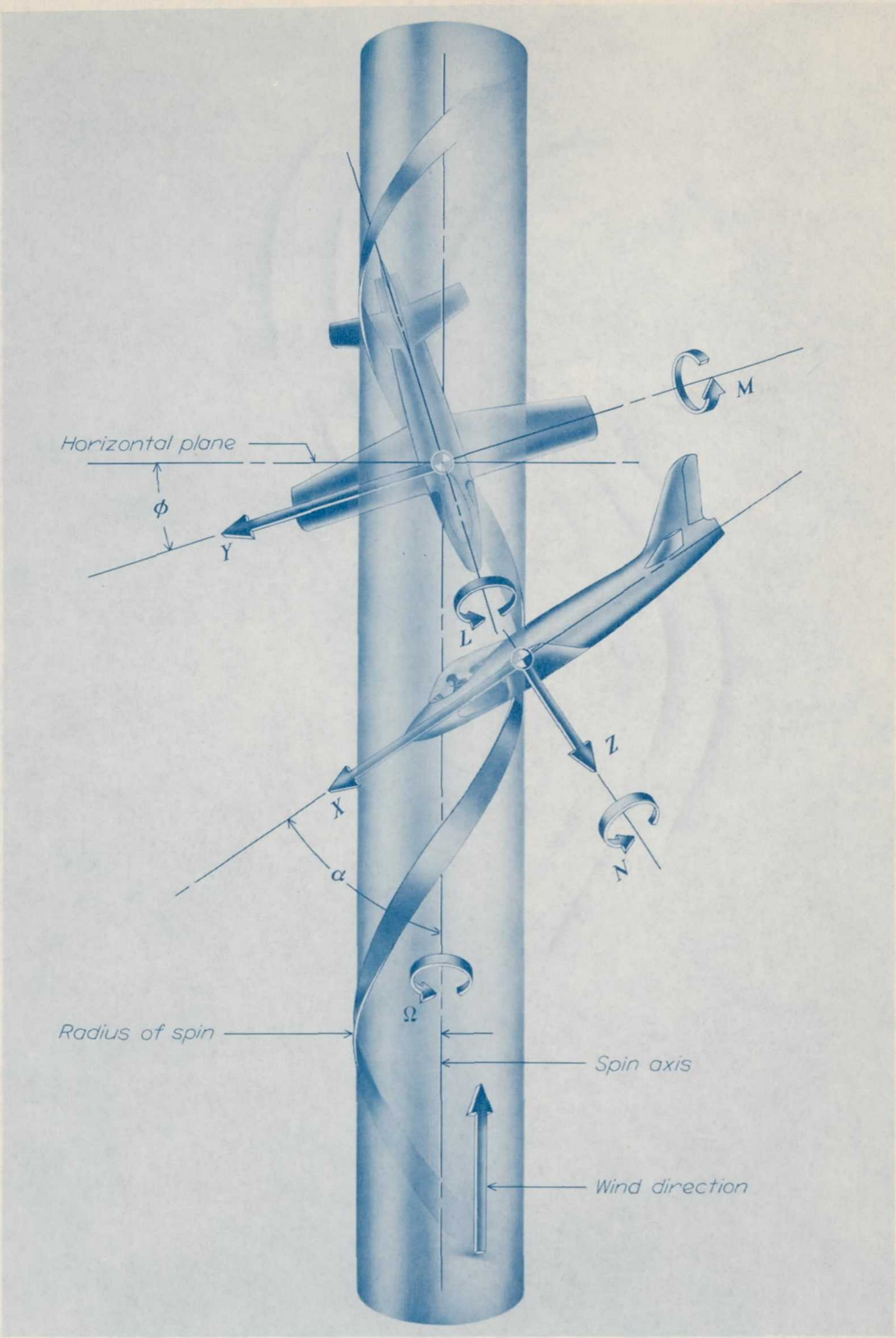

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Figure 1.- Illustration of an airplane in a spin. Arrows indicate positive directions of forces and moments along and about the body axes of the airplane.

CONFIDENTIAL

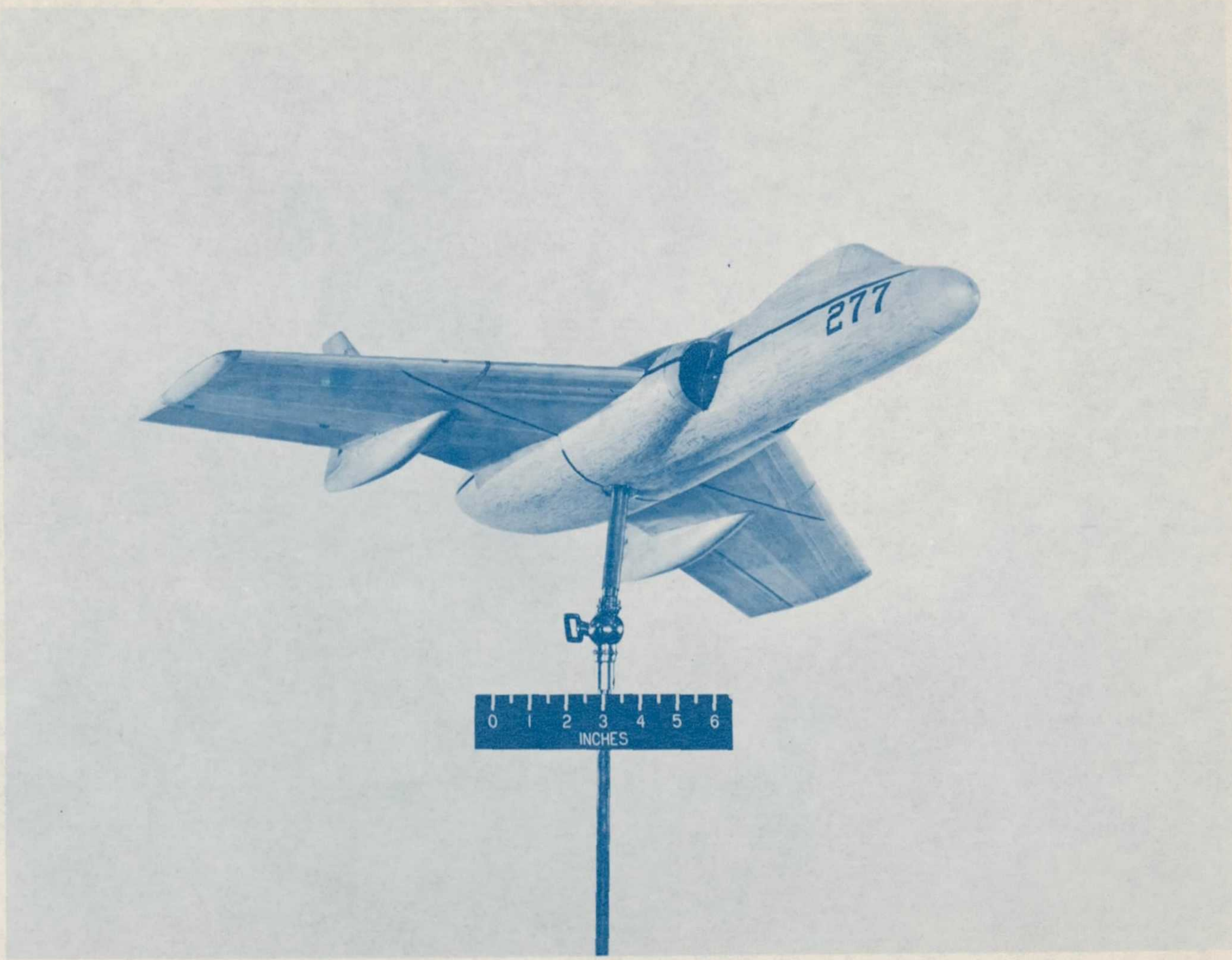

Figure 2.- Photograph of the 1/21-scale model of the Chance Vought F7U-3 airplane.

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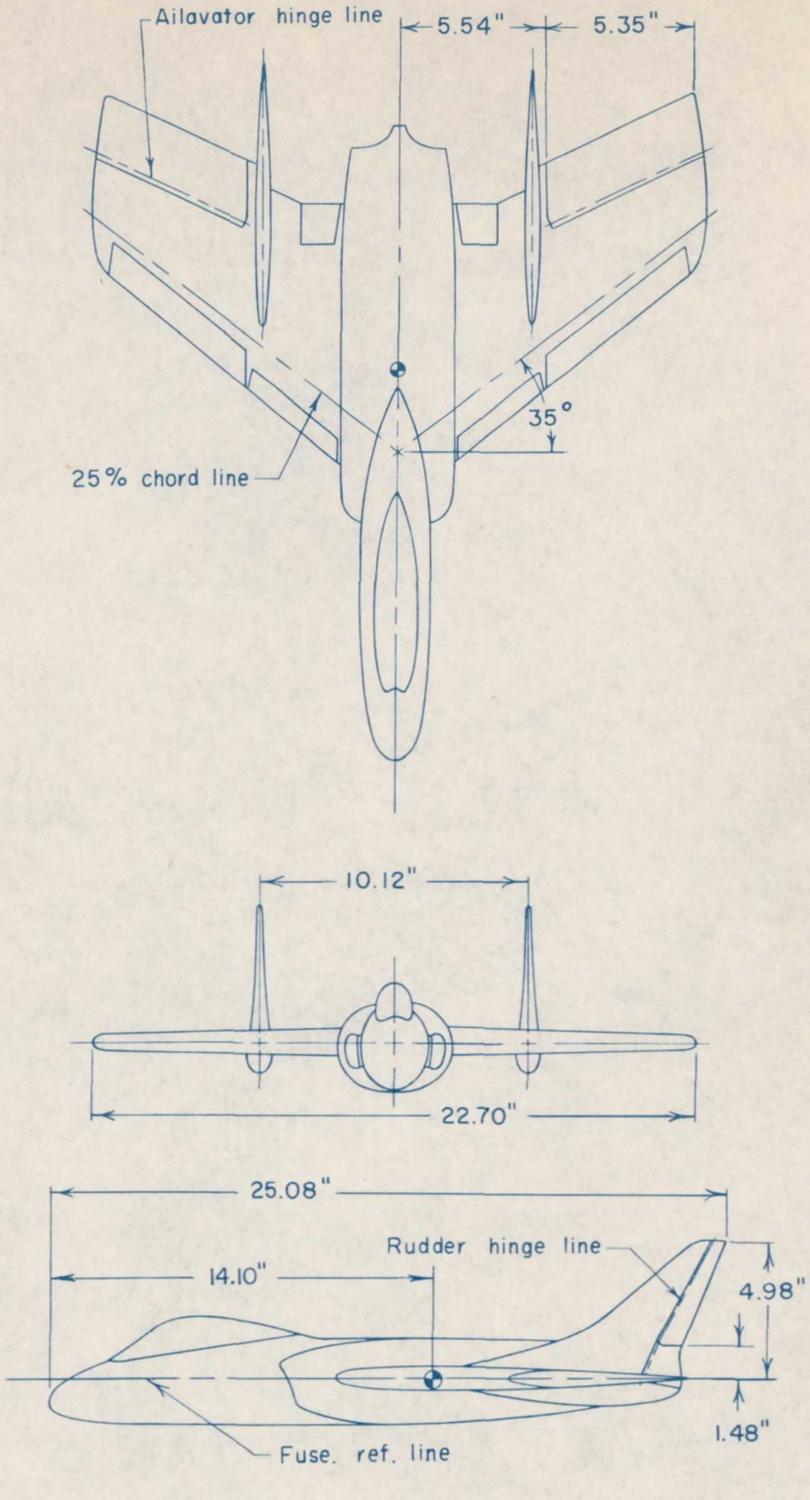

Figure 3.- Three-view drawing of the 1/21-scale model of the Chance Vought F7U-3 airplane as tested in the Langley 20-foot free-spinning tunnel. Dimensions are model values. Center-of-gravity position shown is for the combat-loading condition.

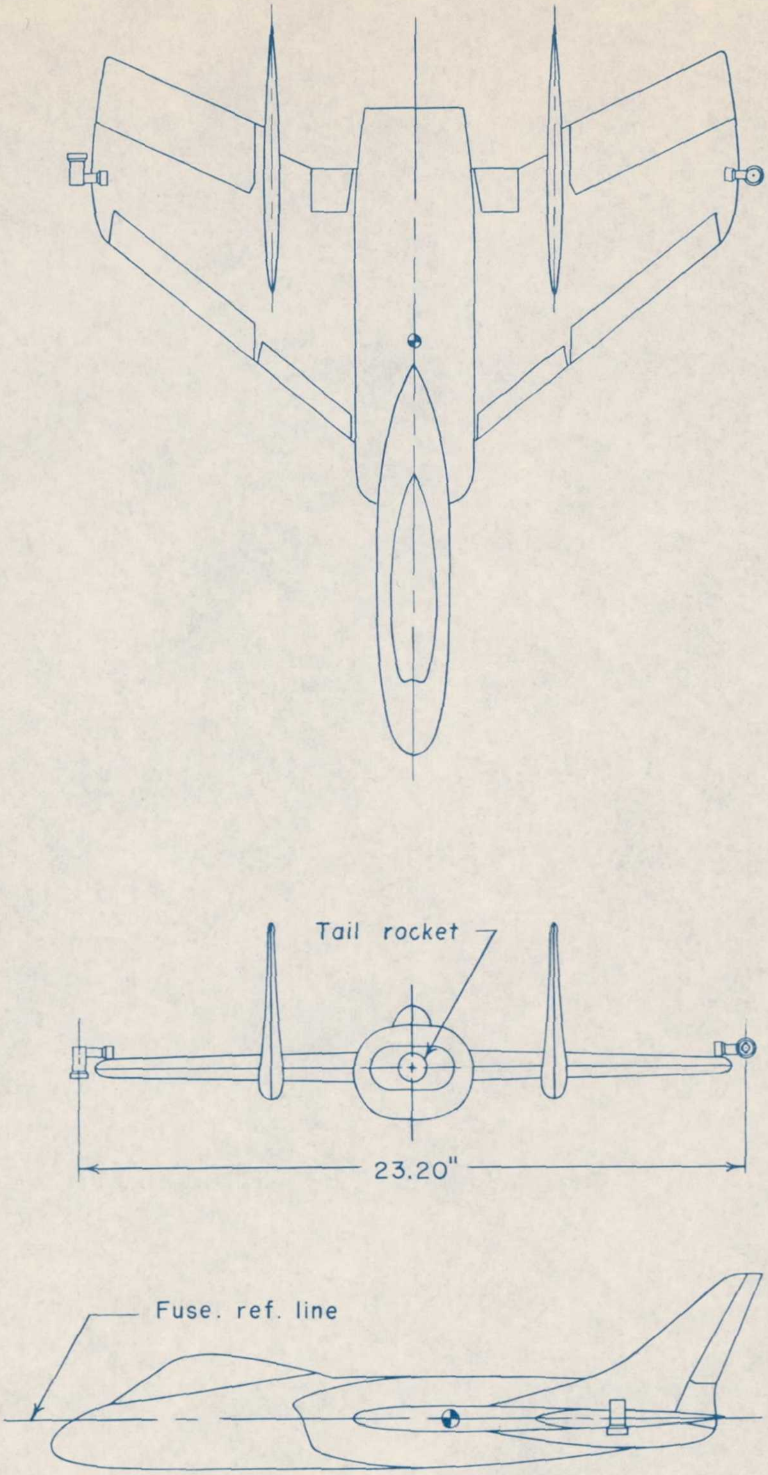

Figure 4.- Three-view drawing of the 1/21-scale model of the Chance Vought F7U-3 airplane with rockets installed as tested in the Langley 20-foot free-spinning tunnel. Dimension is model value.

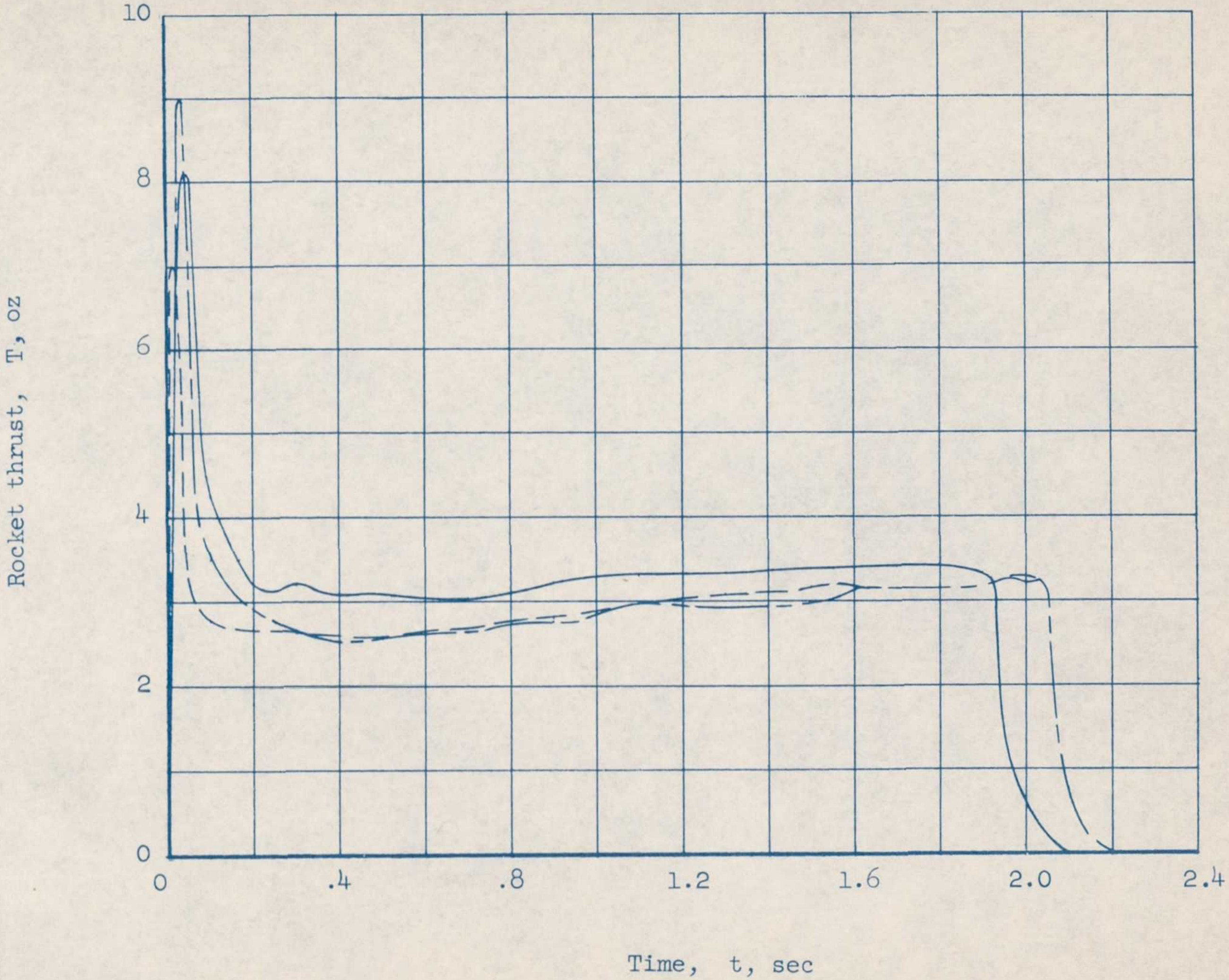

Figure 5.- Variation of thrust of small model rocket with time for several rocket tests showing repeatability of firings.

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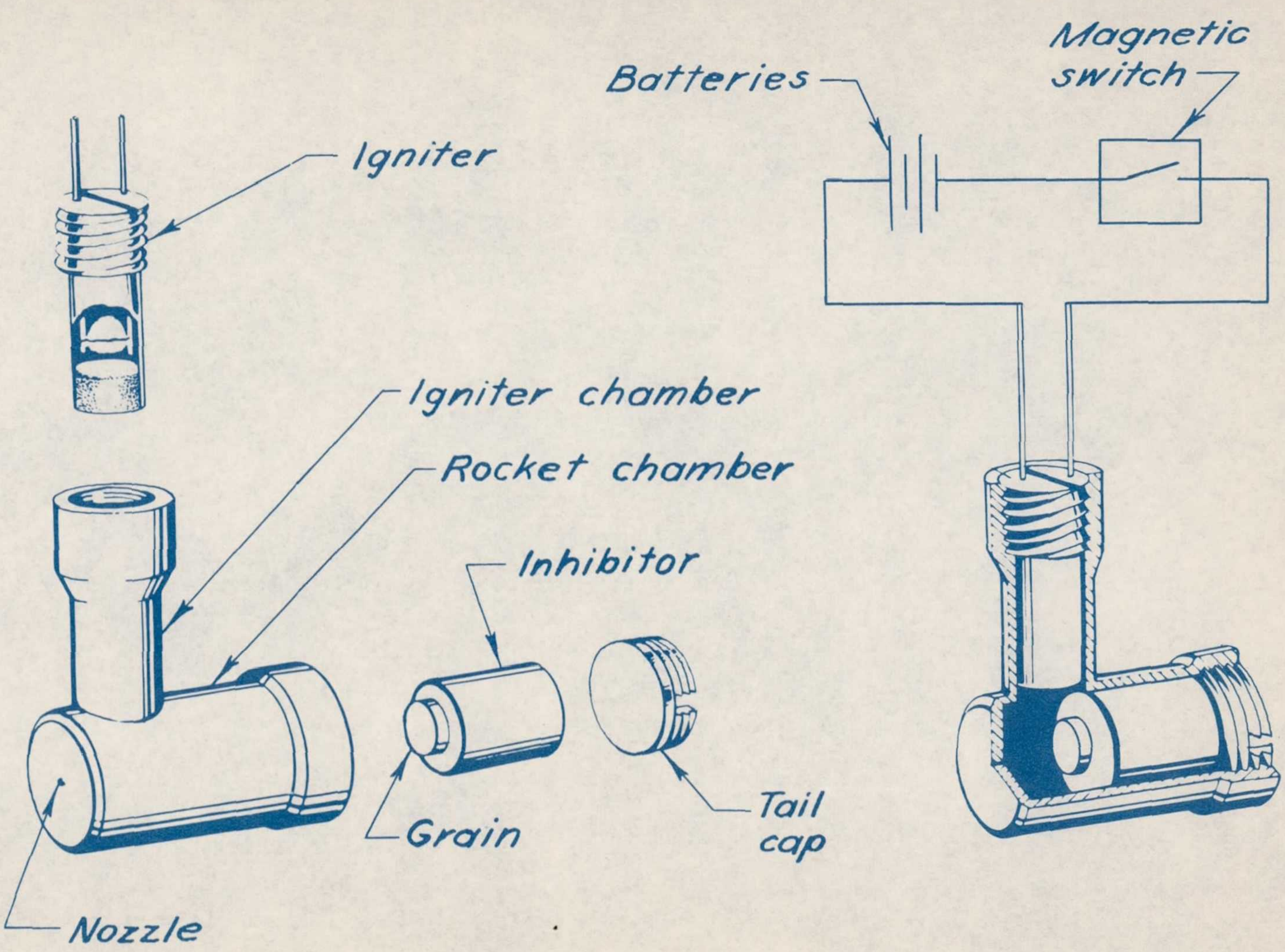

Figure 6.- Sketch of small model rocket showing the various parts including the electrical circuit.

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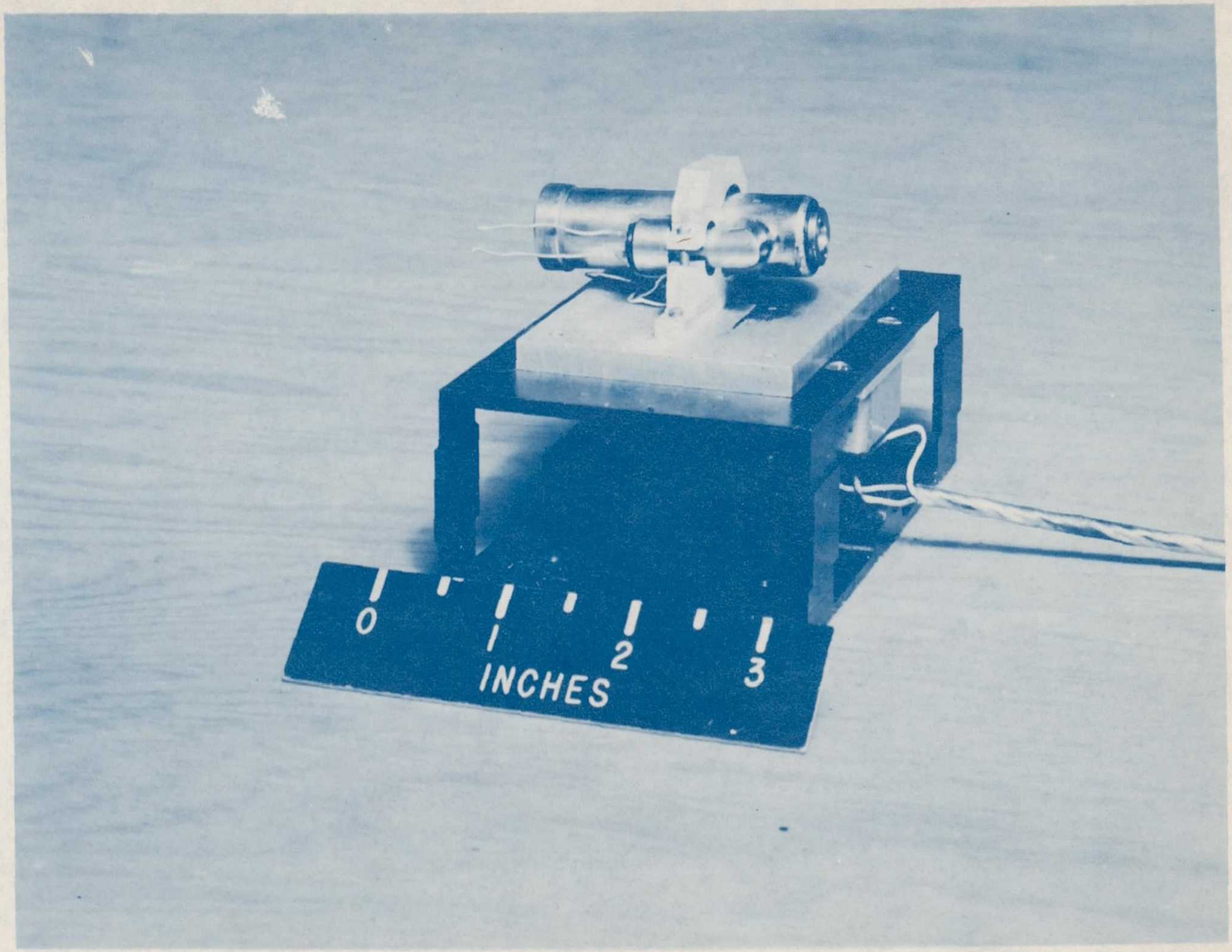

L-86732

Figure 7.- Photograph of the large intermediate model rocket (shown mounted on a test stand) used to simulate the effect of thrust on the 1/21-scale model of the Chance Vought F7U-3 airplane.

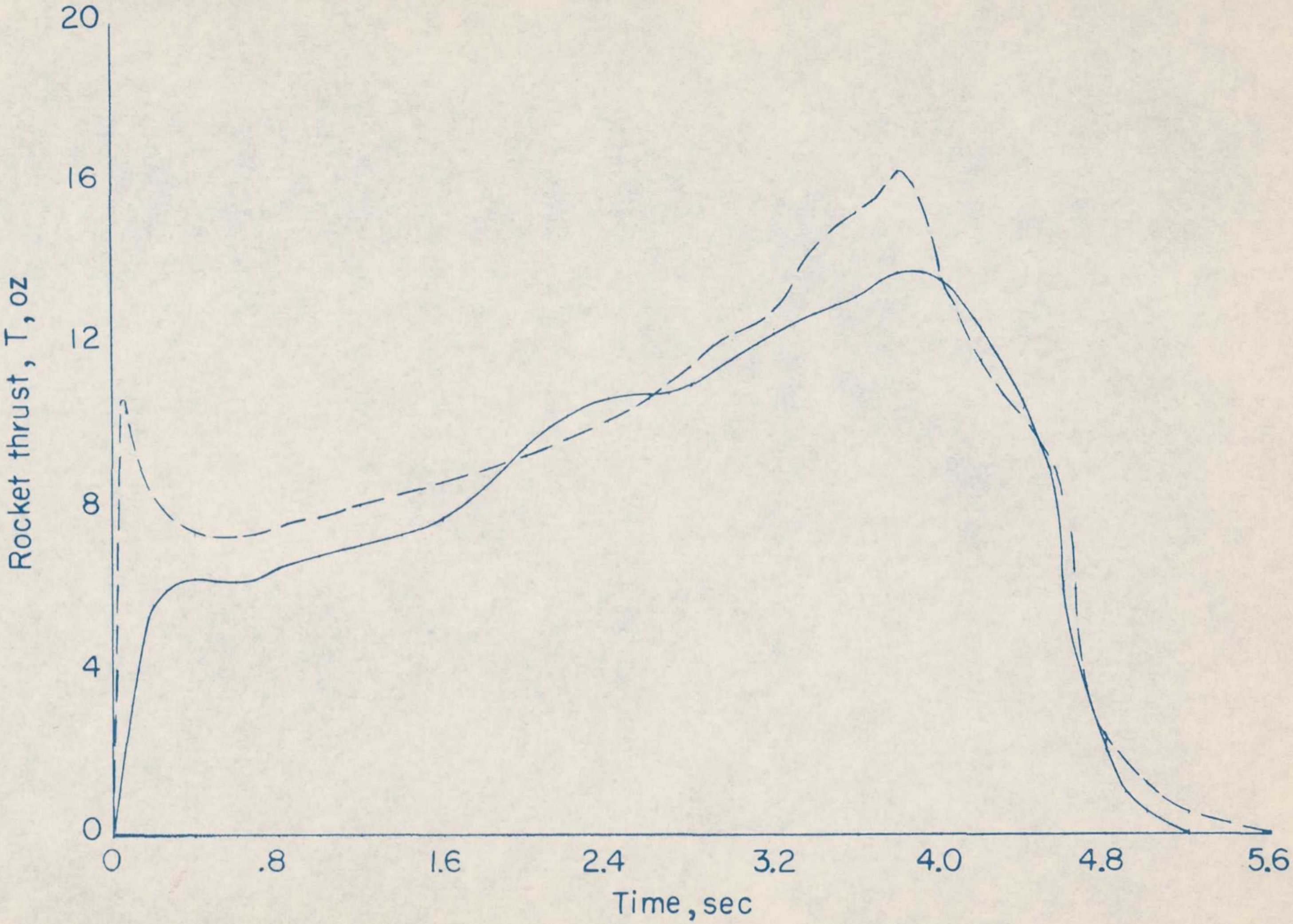

Figure 8.- Variation of thrust of large intermediate model-rocket with time for two rocket tests showing repeatability of firings.

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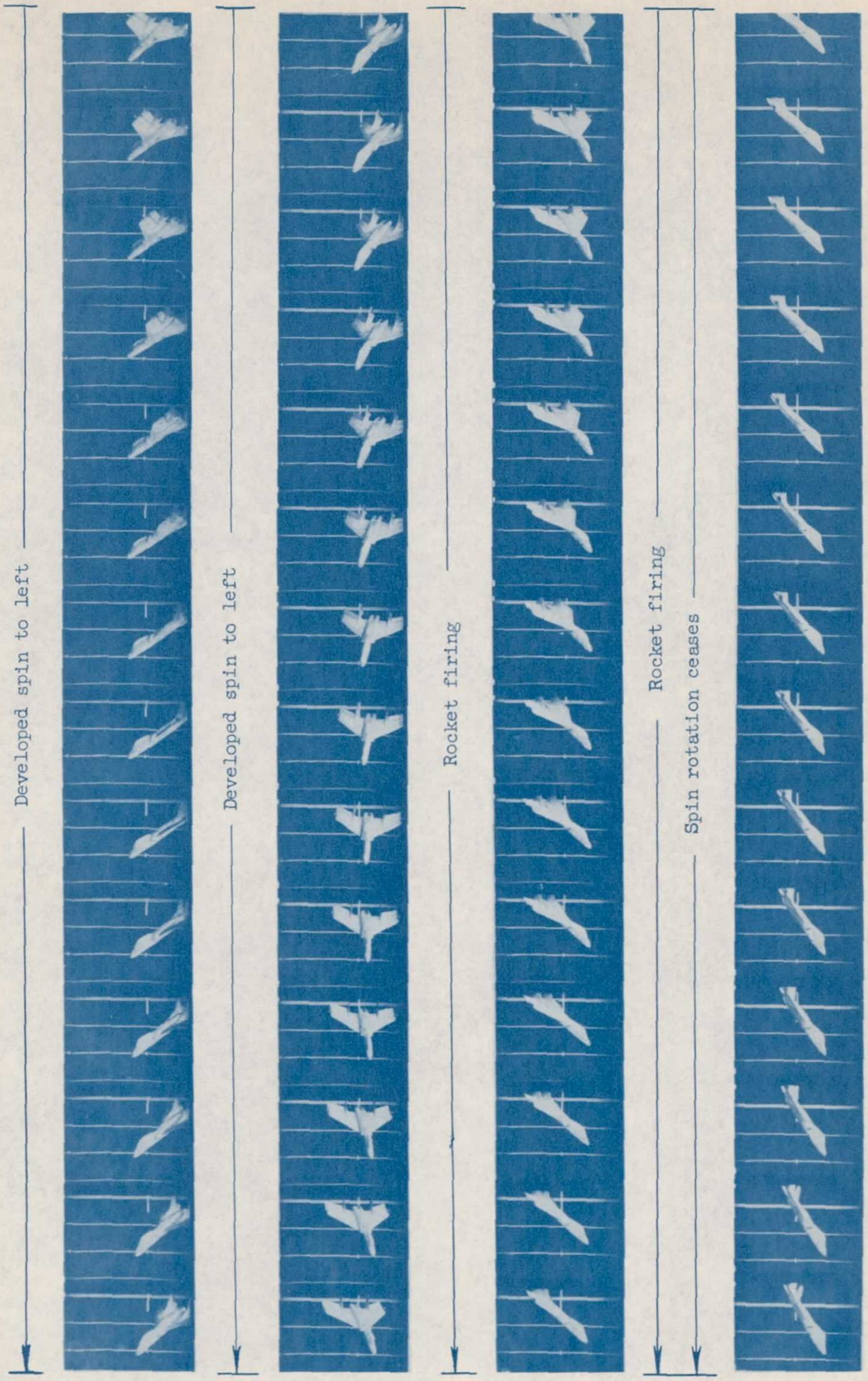
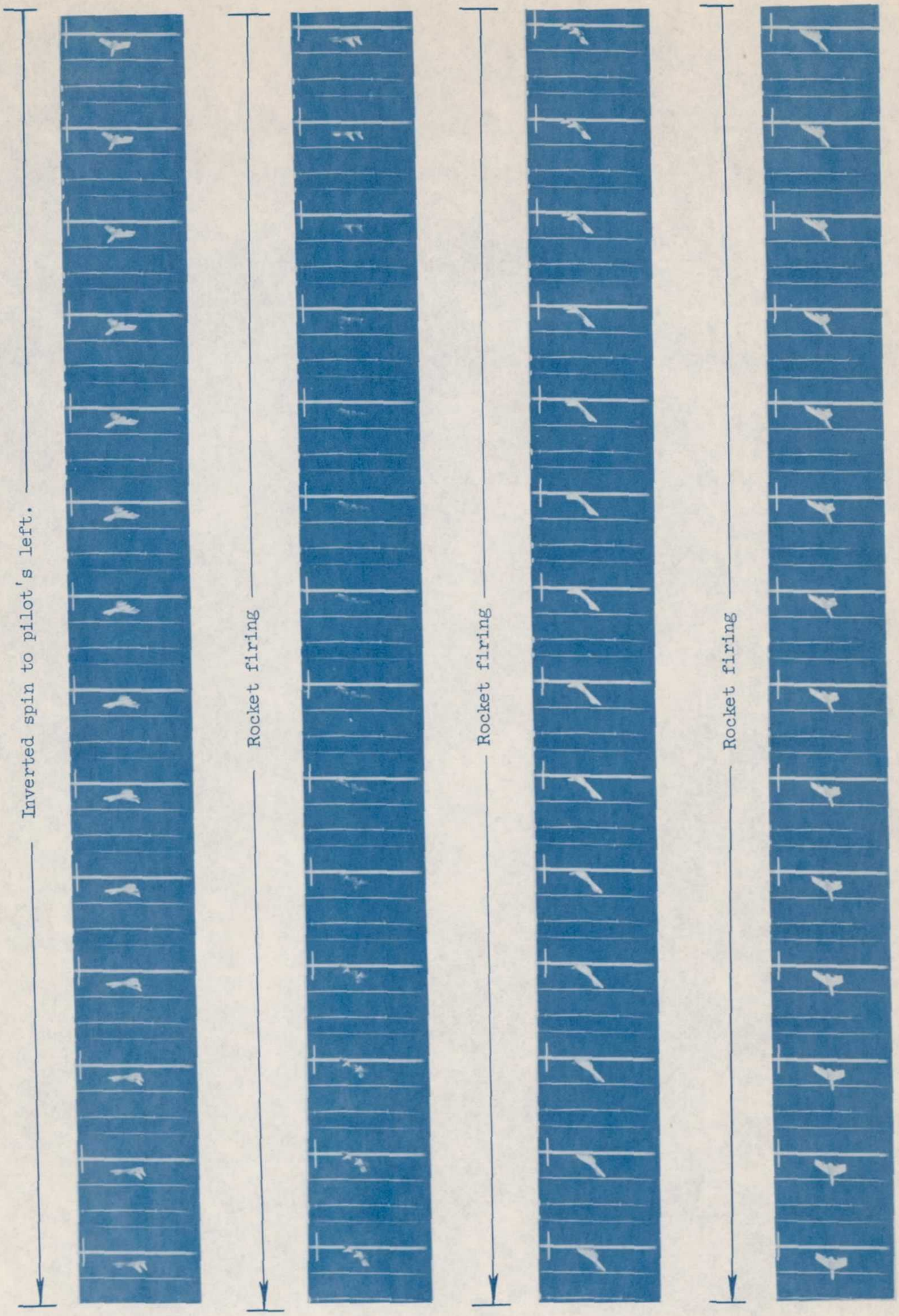


L-87512

Figure 9.- Typical motion of the 1/21-scale model of the Chance Vought F7U-3 airplane recovering from a left erect spin by firing a yaw rocket on the outboard wing tip. Film speed, 64 frames per second.

Figure 9.- Concluded. L-87513



L-87514

Figure 10.- Typical motion of the 1/21-scale model of the Chance Vought F7U-3 airplane recovering from an inverted spin to the pilot's left by firing a yaw rocket on the outboard wing tip. Film speed, 64 frames per second.

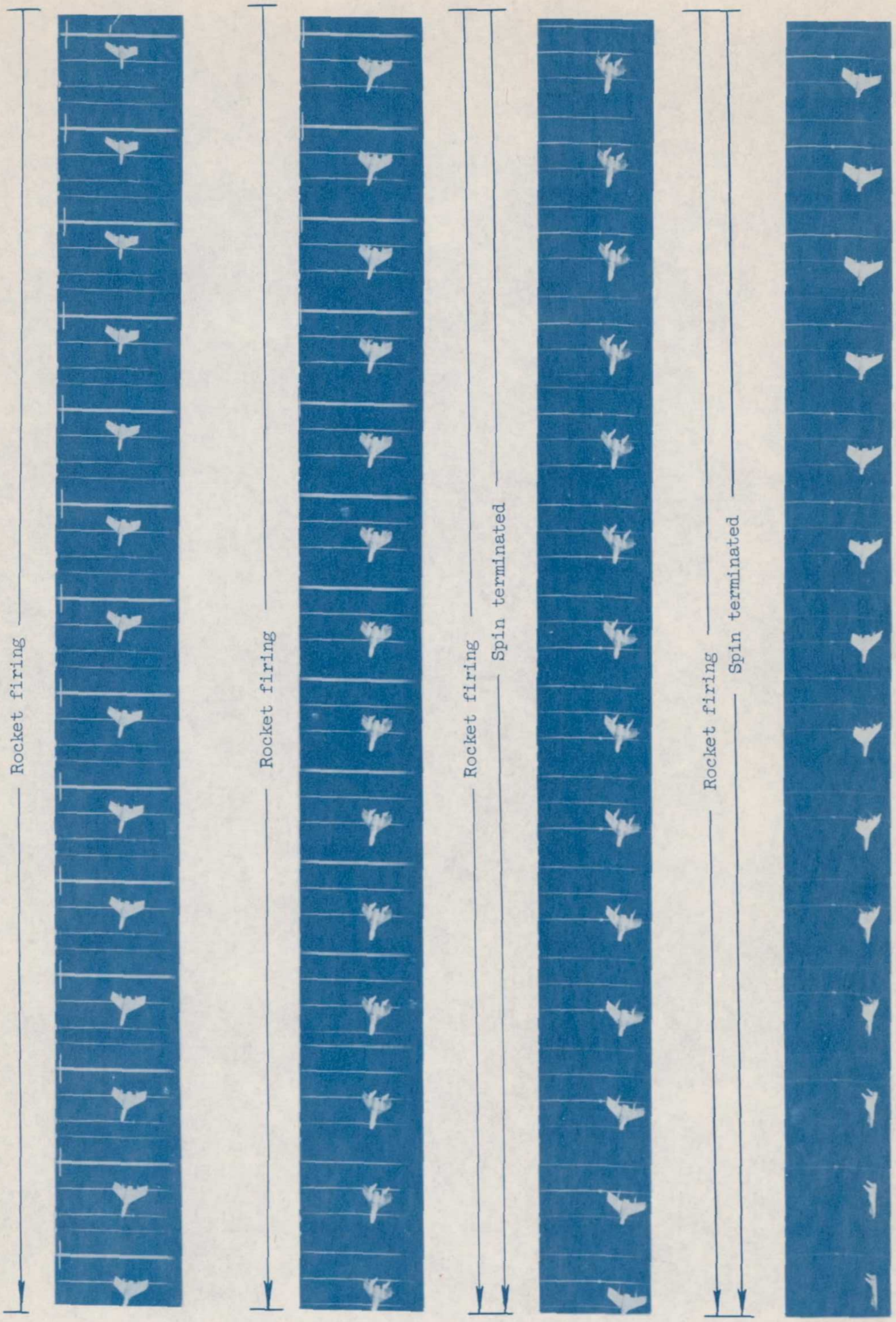
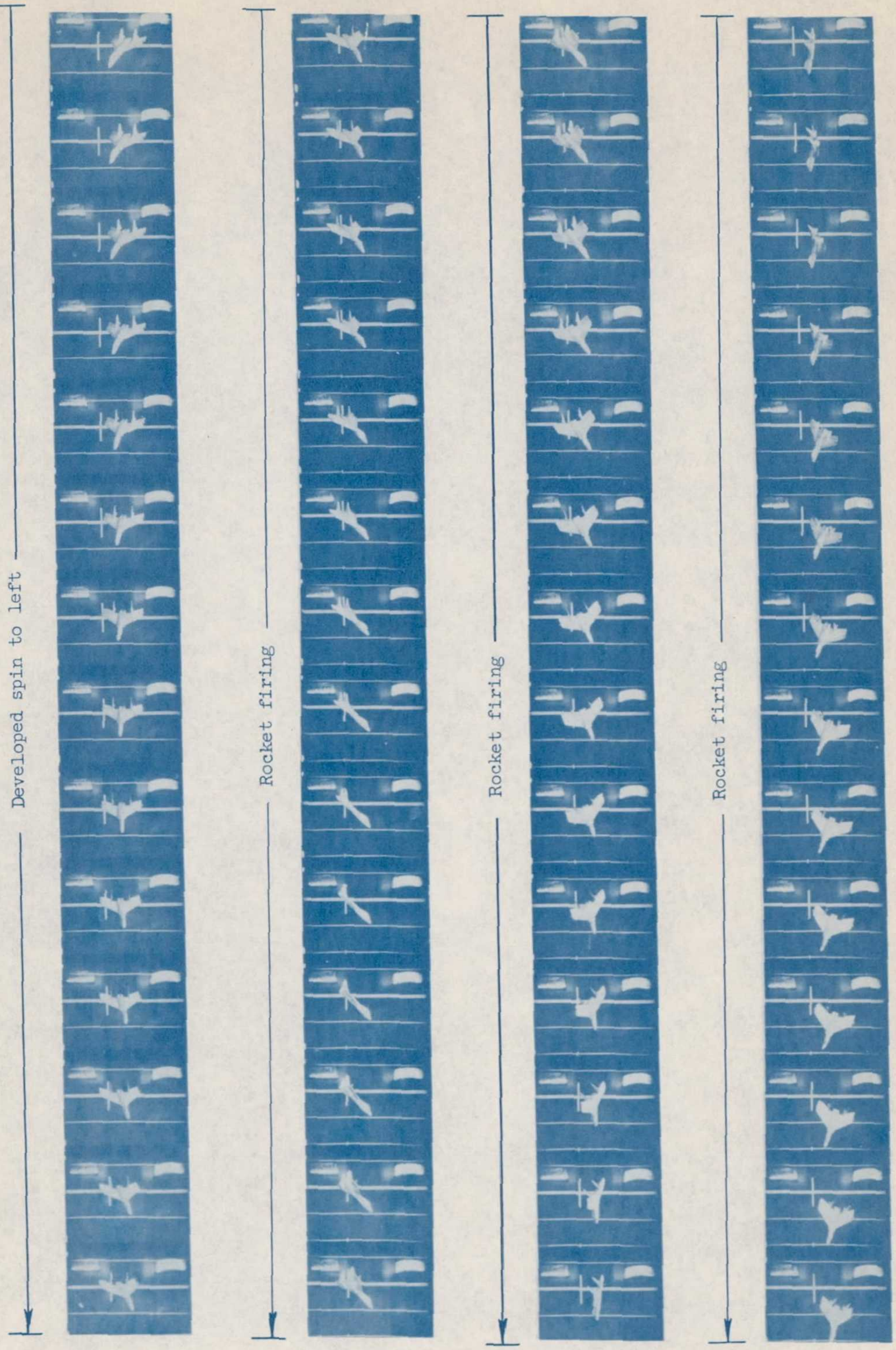


Figure 10.- Concluded. L-87515



L-87516

Figure 11.- Typical motion of the 1/21-scale model of the Chance Vought F7U-3 airplane recovering from a left erect spin by firing a roll rocket on the outboard wing tip. Film speed, 64 frames per second.

bottom cut off

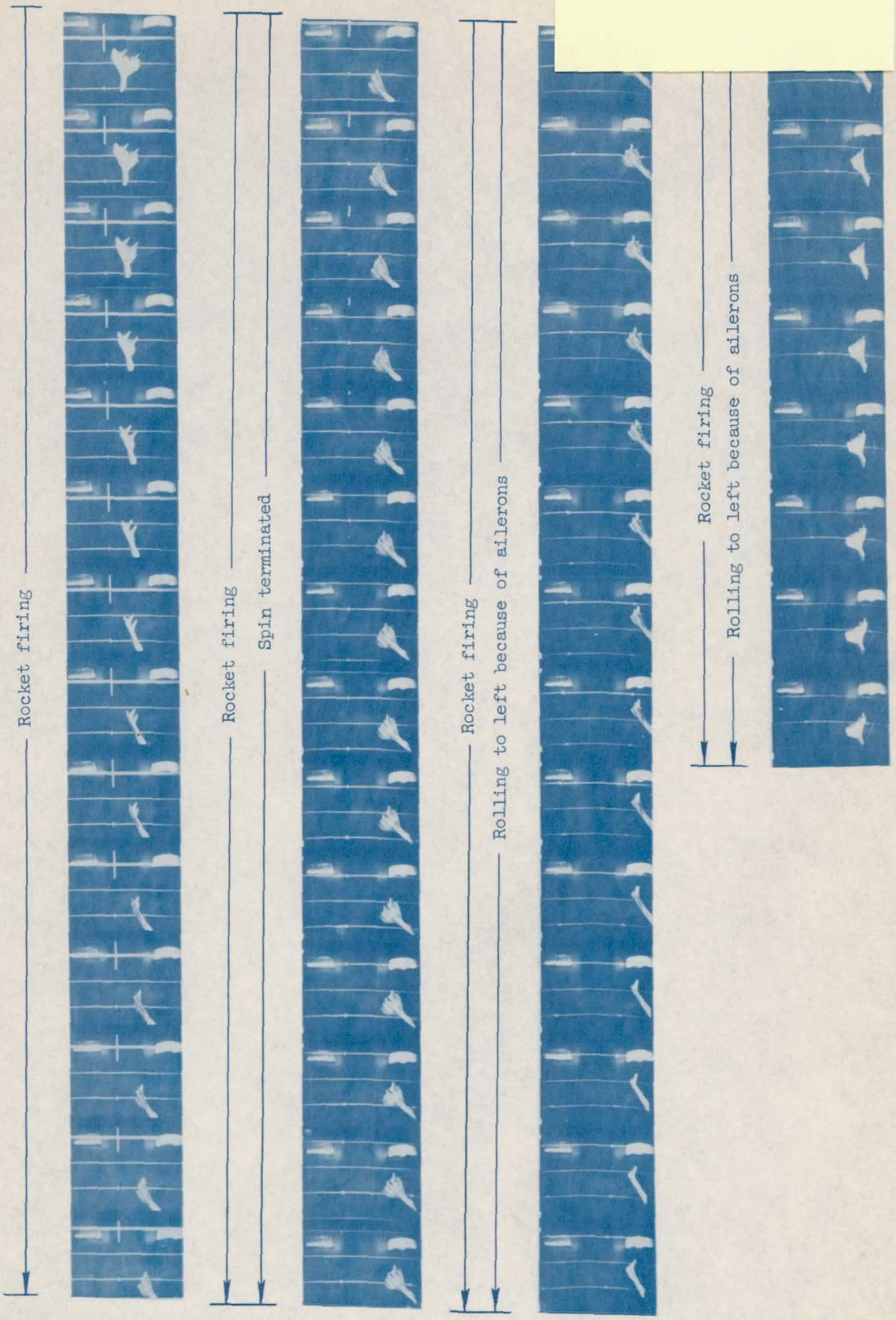
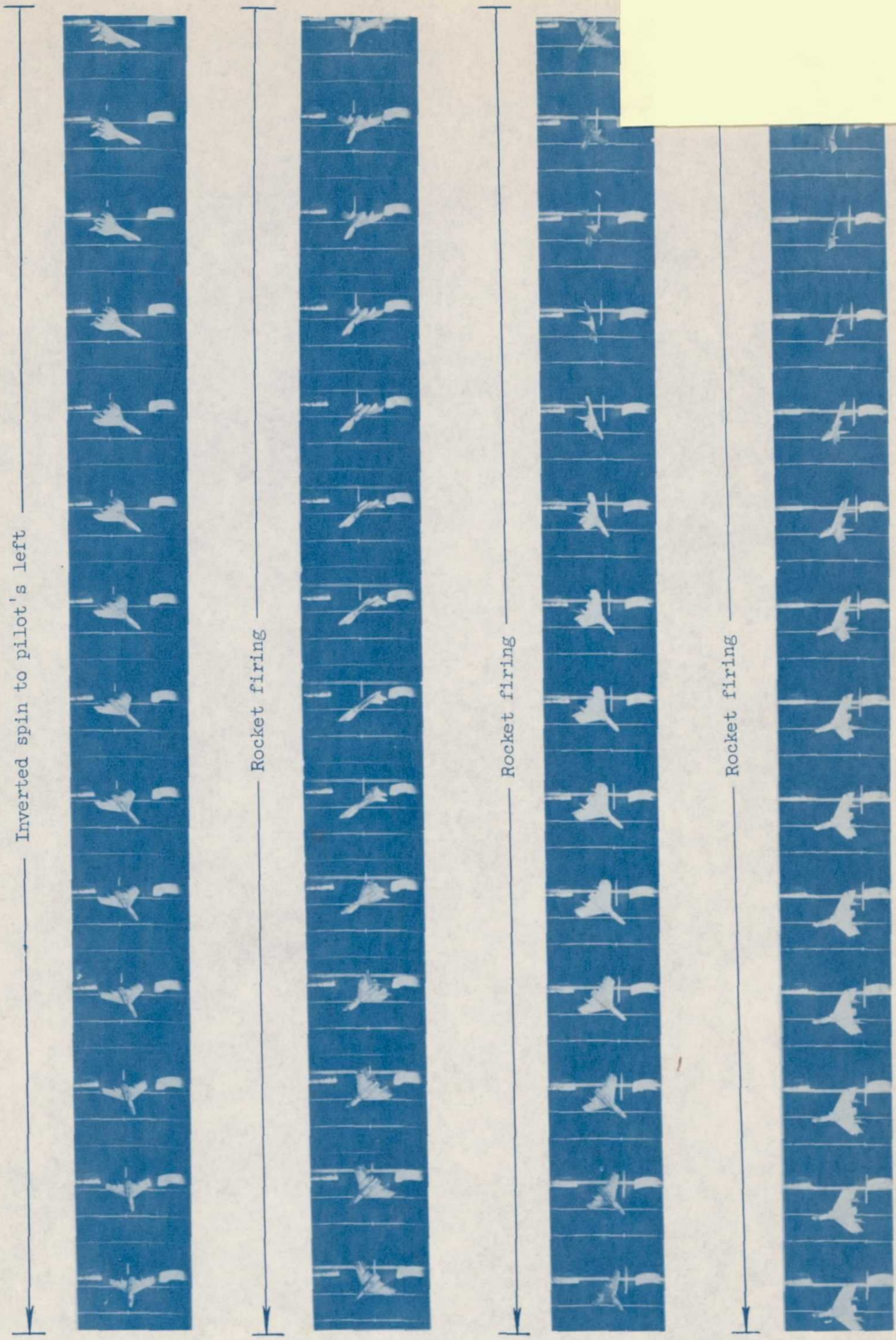
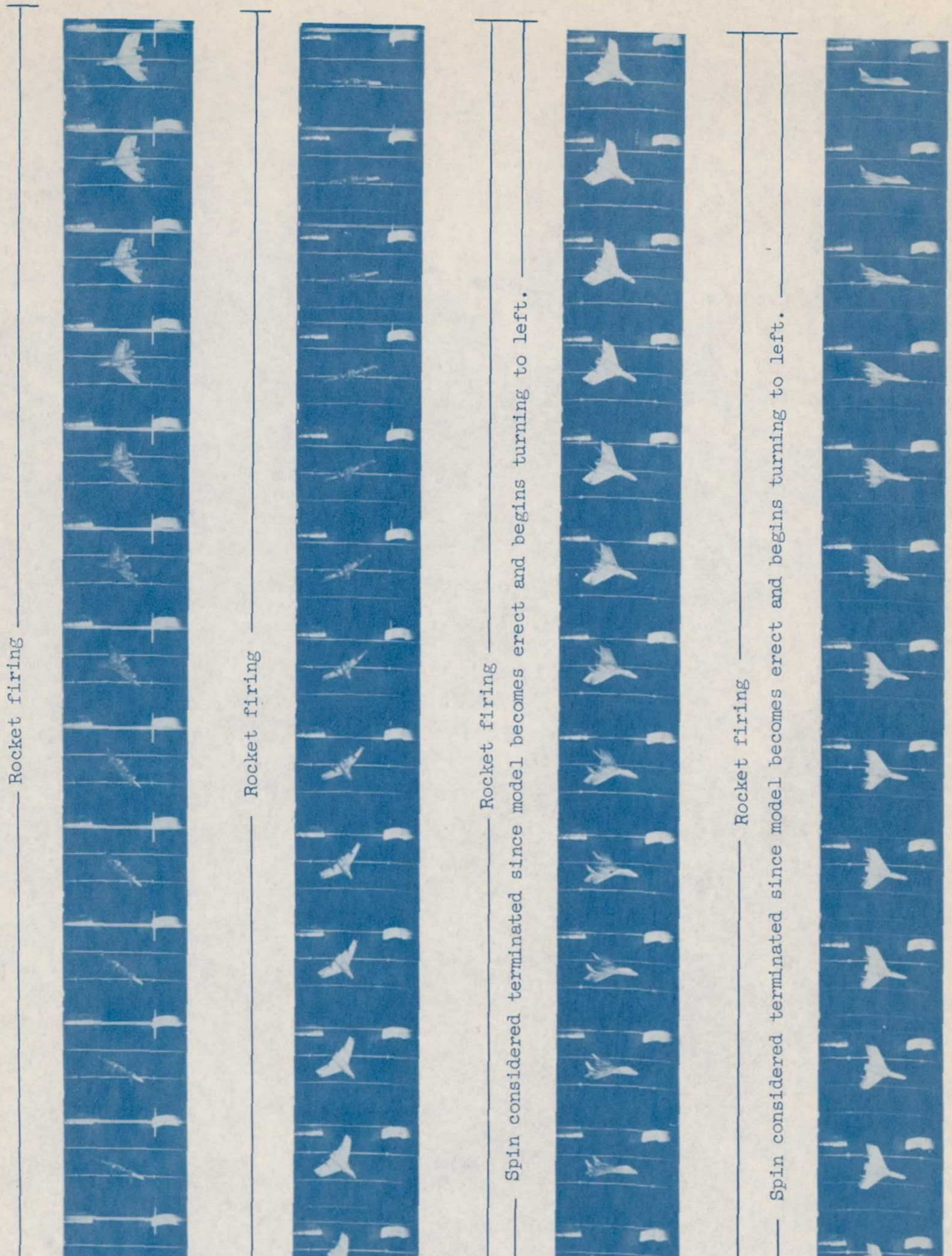


Figure 11.- Concluded. L-87517



L-87518

Figure 12.- Typical motion of the 1/21-scale model of the Chance Vought F7U-3 airplane recovering from an inverted spin to the pilot's left by firing a roll rocket on the outboard wing tip. Film speed, 64 frames per second.



L-87519

Figure 12.- Concluded.