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# RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

## FREE-SPINNING AND RECOVERY CHARACTERISTICS OF A 1/19-SCALE MODEL OF THE NORTH AMERICAN T-28C AIRPLANE

TED NO. NACA AD 3127

By James S. Bowman, Jr.

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Langley Field, Va.



NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

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## SUMMARY

An investigation has been conducted in the Langley 20-foot free-spinning tunnel on a 1/19-scale model of the North American T-28C airplane to determine the spin and recovery characteristics. The T-28C airplane is similar to the T-28B airplane except for slight modifications for the arresting hook. The lower rear section of the fuselage was cut out and, consequently, the lower part of the rudder was removed to make a smooth fairing with the fuselage. The T-28B airplane had good recovery characteristics; but these modifications, along with the addition of gun packages on the wings, led to poor and unsatisfactory spin-recovery characteristics during demonstration spins of the T-28C airplane.

Model test results indicated that without the gun packages installed, satisfactory recoveries could be obtained if the elevators were held full back while the rudder was fully reversed and the ailerons were held neutral. However, with the addition of gun packages to the wings and the corresponding change in loading, recoveries were considered unsatisfactory. Recoveries attempted by using a larger chord or larger span rudder were improved very slightly, but were still considered marginal or unsatisfactory. Strakes placed on the nose of the model were effective in slowing the spin rotation slightly and, in most instances, decreased the turns for recovery slightly. Recovery characteristics were slightly marginal for the full fuel loading when strakes and the extended-chord rudder were installed; but with the wing fuel partly used, recovery characteristics were again considered unsatisfactory or, at least, definitely on the marginal side. The optimum control technique for recovery is movement of the rudder to full against the spin with the stick held full back (elevators full up) and the ailerons held neutral, followed by forward movement of the stick only after the spin rotation ceases. Inverted-spin test results indicate that the airplane will spin steep and fast and that recovery by full rudder reversal will be satisfactory if the ailerons are held neutral.

## INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, an investigation has been conducted in the Langley 20-foot free-spinning tunnel on a 1/19-scale model to determine the spin and recovery characteristics of the North American T-28C airplane.

The T-28C airplane is, for the most part, the same as the T-28B airplane except for a cutout for the arresting hook on the lower rear section of the fuselage and the removal of the lower part of the rudder to make a smooth fairing with the fuselage. (See fig. 1.) The T-28B airplane had good recovery characteristics, but the preceding modifications along with the addition of gun packages on the wings led to poor and unsatisfactory spin-recovery characteristics on the T-28C airplane during demonstration spins. The model investigation was conducted to determine how the recovery characteristics could be improved. Alternate vertical-tail configurations were tested on the model at the request of North American Aviation, Inc., to determine their effect on spin recovery. As suggested by the National Advisory Committee for Aeronautics, strakes of various sizes were also tested on the model.

The normal loading with full fuel and a loading with 55 percent fuel were spin tested on the model both erect and inverted. All tests were conducted with the center of gravity located at 25 percent of the mean aerodynamic chord.

An appendix is included which presents a general description of the model testing technique, the precision with which model test results and mass characteristics are determined, variations of model mass characteristics occurring during tests, and a general comparison between available model and airplane results.

## SYMBOLS

| | |
|---|---|
| $b$ | wing span, ft |
| $S$ | wing area, sq ft |
| $\bar{c}$ | 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) |

| | |
|---|---|
| $m$ | mass of airplane, slugs |
| $I_X$, $I_Y$, $I_Z$ | 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 |
| $\rho$ | air density, slugs/cu ft |
| $\mu$ | relative density of airplane, $\frac{m}{\rho Sb}$ |
| $\alpha$ | angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg |
| $\phi$ | angle between span axis and horizontal, deg |
| $V$ | full-scale true rate of descent, ft/sec |
| $\Omega$ | full-scale angular velocity about spin axis, rps |

## MODEL AND TEST CONDITIONS

The 1/19-scale model of the North American T-28C airplane used in the investigation was built and prepared for testing by the Langley Laboratory of the National Advisory Committee for Aeronautics. The model was originally built to represent the T-28B airplane for a previous investigation, but was modified to represent the T-28C. A three-view drawing of the T-28C model is shown in figure 1. Tests were conducted with the model in the clean condition and with gun packages installed. Three rudders of different sizes, which were designed by North American Aviation, Inc., were used on the model for tests. These included the original rudder for the T-28C, a rudder with increased chord (Mark V), and a rudder with increased span and chord (Mark VI). (See fig. 2.)

A strake as used in this report is defined as a very low-aspect-ratio thin sheet of aluminum alloy located on the nose (part of fuselage located forward of the wing leading edge) at or near half the depth of the fuselage. (See fig. 3.) The purpose of the strake is to change the air flow around the nose of the airplane.

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 20,000 feet ($\rho$ = 0.001267 slug/cu ft). The mass characteristics and inertia parameters for loadings possible on the airplane and for the loadings tested on the model are indicated in table II.

The maximum control deflections (measured perpendicular to the hinge lines) used on the model during tests were:

| | |
|---|---|
| Rudder, deg | 25 right, 25 left |
| Increased rudder deflection, deg | 30 right, 30 left |
| Ailerons, deg | 16.3 up, 9.7 down |
| Elevators, deg | 25 up, 15 down |
| Increased elevator deflection, deg | 30 up, 15 down |

## RESULTS AND DISCUSSION

The results of model tests are presented in charts 1 to 10 and in table III. Test results were similar to the right and left; therefore, all results are arbitrarily presented in terms of spins to the pilot's right.

### Erect Spins

Model test results indicated that the aileron position generally had only little effect on the spin and recovery characteristics but that elevator position had a very large effect. Recoveries attempted with elevators full up (stick back) were much more rapid than with elevators full down (stick forward); these conditions point out that the stick should be held full back for all recovery attempts.

Tests conducted with the model in the clean condition indicated that the airplane should have satisfactory-to-marginal recovery characteristics with the original rudder (chart 1), provided that the stick is held back. However, with the addition of the gun packages to the wings and the corresponding change in loading, recoveries were considered unsatisfactory (chart 2). Test results indicated that increasing the distance between the gun packages and wings by means of pylons (chart 3) still resulted in unsatisfactory recovery characteristics. The pylons were tested because the manufacturer was considering their use.

Tests were conducted to determine the aerodynamic effects of the gun packages by replacing the gun packages with an equivalent lead weight. These results (chart 4) showed that the change in the spinning and recovery characteristics from the clean condition due to adding the gun packages was due to the change in loading and not to the aerodynamic shape of the gun package. All further tests, therefore, were conducted with the gun package replaced with weights for convenience of testing.

The tests conducted with the larger Mark V and Mark VI rudders are presented in charts 5 and 6, respectively, for the gun-package loading and 100 percent fuel. These results indicated that, although slightly improved over the recoveries obtained by the original rudder, the recoveries were still unsatisfactory. The results obtained with the Mark V and Mark VI rudders were similar and most of the additional erect-spin tests were arbitrarily conducted by using the Mark V rudder.

Inasmuch as the use of strakes in previous tests of another model in the Langley 20-foot free-spinning tunnel indicated that a slower spin might be obtained, strakes of various sizes were tested on the nose of the model in an attempt to improve the spin-recovery characteristics. The size strakes tested and the positions used are presented in figure 3. Strake A in position 1 (fig. 3) was found to be somewhat favorable, and the results are presented in chart 7. Results of tests for other strakes tested are shown in table III. Strake A in position 1 was effective in slowing the spin rotation slightly and, in most instances, decreased the number of turns for recovery very slightly. Recovery characteristics obtained with this configuration for full fuel loading were satisfactory. With fuel partly used, however, the recovery characteristics were considered unsatisfactory (chart 8).

All the test results indicated that movement of the rudder to full against the spin with stick held full back (elevators full up) and ailerons held neutral, followed by forward movement of the stick only after the spin rotation ceases was the optimum control technique for recovery. Based on spin-test results for this model, the configuration which gives the best recoveries has strake A in position 1 with either the Mark V or Mark VI rudder.

Table III presents the results of tests with increased rudder and elevator deflections and results of tests with an antispin fillet and ventral fin, in addition to the results of tests conducted with strakes of various sizes at several positions. For the gun-package loading and full fuel, the results were as follows: Strakes A, B, and C in position 1 with the original rudder gave slightly, if any, improved results over the original rudder alone. However, as noted previously, strake A in position 1 was good with the Mark VI rudder. Strake D in position 1 was unsatisfactory with the Mark V rudder. Some improvement was obtained over the original rudder by using the Mark VI rudder and strake E in positions 1, 2, and 3. The recovery characteristics were marginal for positions 1 and 3, and satisfactory for position 2.

Tests with increased rudder and elevator deflections with the Mark V rudder showed no improvement over the normal control deflections. Similar results were obtained with increased elevator and increased rudder and elevator deflections with the Mark VI rudder. The antispin fillet and ventral fin (shown in fig. 4) with the Mark VI rudder offered no improvement over the Mark VI rudder alone.

For the gun-package loading and 55 percent fuel, strake B in position 1 for both the original and Mark VI rudders indicated unsatisfactory recovery characteristics.

## Inverted Spins

The inverted-spin test results are presented in charts 9 and 10. The order used for presenting the data for inverted spins shows controls crossed for the established spin (right rudder pedal forward and stick to pilot's left for a spin to pilot's right) at the right of the chart and stick back at the bottom. When controls are crossed in the established spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion. The angle of wing tilt $\phi$ in the chart is given as up or down relative to the ground.

The inverted-spin test results indicate that, if the airplane does spin in an inverted position, the spin will be steep and fast and recovery by full rudder reversal should be satisfactory if ailerons are maintained neutral.

## SUMMARY OF RESULTS

Based on results of spin tests of a 1/19-scale model of the T-28C airplane, the following results regarding the spin and recovery characteristics of the T-28C airplane at an altitude of 20,000 feet are made:

1. Elevator position will have a very large effect on the spin and recovery characteristics: stick full back will be conducive to recoveries whereas stick forward will be adverse to recoveries.

2. The adverse changes in the spin and recovery characteristics encountered by the addition of gun packages to the wings will result because of the change in mass distribution and not to any aerodynamic effect of the gun packages.

3. Strakes placed well forward on the nose at or near half the depth of the fuselage should decrease the spin rotation slightly and should decrease the number of turns for recovery slightly.

4. A slight improvement in recoveries over those for the original rudder will be obtained by the use of a larger chord rudder (Mark V) or a larger chord and span rudder (Mark VI).

5. The configuration which will give the best recoveries includes strake A in position 1 with either the Mark V or Mark VI rudder.

6. The optimum technique for erect spin recovery is movement of the rudder to full against the spin with stick held full back (elevators full up) and ailerons held neutral, followed by forward movement of the stick only after the spin rotation ceases.

7. The optimum technique for inverted-spin recovery is reversal of the rudder to full against the spin, while the ailerons are held neutral.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 27, 1956.

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# APPENDIX

## MODEL TESTING TECHNIQUE AND PRECISION

### Model Testing Technique

The operation of the Langley 20-foot free-spinning tunnel is generally similar to that described in reference 1 for the Langley 15-foot free-spinning tunnel except that the model launching technique is different. With the controls set in the desired position, a model is rotated and launched by hand into the vertically rising airstream. After a number of turns in the established spin, a recovery attempt is made by moving one or more controls by means of a remote-control mechanism. After recovery, the model dives into a safety net. The tests are photographed with a motion-picture camera. The spin data obtained from these tests are then converted to corresponding full-scale values by methods described in reference 1.

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a 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 and elevator combinations, including neutral and maximum settings of the surfaces. Recovery is generally attempted by rapid full reversal of the rudder, by rapid full reversal of both rudder and elevator, or by rapid full reversal of the rudder simultaneously with moving ailerons to full with the spin. The particular control manipulation required for recovery is generally dependent on the mass and dimensional characteristics of the model. (See refs. 2 and 3.) 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, which may be either against the spin (stick left in a right spin) or with the spin, depending primarily on the mass characteristics of the particular model. Recovery is attempted by rapidly reversing the rudder from full with the spin to only two-thirds against the spin, by simultaneous rudder reversal to two-thirds against the spin, and movement of the elevator to either neutral or two-thirds down, or by simultaneous rudder reversal to two-thirds against the spin and stick movement to two-thirds with the spin. This control configuration and manipulation is referred to as the "criterion spin," with the particular control settings and manipulation used being dependent on the mass and dimensional characteristics of the model.

Turns for recovery are measured from the time the controls are moved for recovery until the time the spin rotation ceases. Recovery characteristics of a model are generally considered satisfactory if recovery attempted from the criterion spin in any of the manners previously described is accomplished within two and one-fourth turns. This value has been selected on the basis of spin-recovery data of full-scale airplanes that are available for comparison with corresponding model test results.

For spins in which a model has a rate of descent in excess of that which can readily be obtained in the tunnel, the rate of descent is recorded as greater than the velocity at the time the model hit the safety net; for example, greater than 300 feet per second, full scale. In such tests, the recoveries are attempted before the model reaches its final steeper attitude and while it is still descending in the tunnel. Such results are considered conservative; that is, recoveries are generally not as fast as when the model is in the final steeper attitude. For recovery attempts in which a 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 were moved to the time the model struck the net, as greater than three. A recovery greater than three turns, however, does not necessarily indicate an improvement over a recovery greater than seven turns. A recovery of ten or more turns is indicated as $\infty$. When a model recovers without control movement (rudder held with the spin), the results are recorded as "no spin."

## Precision

Results determined in free-spinning tunnel tests are believed to be true values given by models within the following limits:

| | |
|---|---|
| $\alpha$, deg . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | $\pm 1$ |
| $\phi$, deg . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | $\pm 1$ |
| V, percent . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | $\pm 5$ |
| $\Omega$, percent . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | $\pm 2$ |
| Turns for recovery obtained from motion-picture records . . . . . | $\pm\frac{1}{4}$ |
| Turns for recovery obtained visually . . . . . . . . . . . . . . . | $\pm\frac{1}{2}$ |

The preceding limits may be exceeded for certain spins in which it is 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.

The accuracy of measuring the weight and mass distribution of models 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 are set with an accuracy of $\pm 1^{\circ}$.

## Variations in Model Mass Characteristics

Because it is impracticable to ballast models exactly and because of inadvertent damage to models during tests, the measured weight and mass distribution of the T-28C model varied from the true scaled-down values within the following limits:

| | |
|---|---|
| Weight, percent | 0 to 4 high |
| Center-of-gravity location, percent $\bar{c}$ | 1 forward to 1 rearward |
| Moments of inertia: | |
| $I_X$, percent | 1 low to 4 high |
| $I_Y$, percent | 0 to 5 high |
| $I_Z$, percent | 2 low to 3 high |

## Comparison Between Model and Airplane Results

Comparison between model and full-scale results in reference 4 indicated that model tests accurately 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, such as motions in the developed spin and proper recovery techniques. The airplanes generally spun at an angle of attack closer to $45^{\circ}$ than did the corresponding models. The comparison presented in reference 4 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, 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.

## REFERENCES

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2. Neihouse, A. I.: A Mass-Distribution Criterion for Predicting the Effect of Control Manipulation on the Recovery From A Spin. NACA WR L-168, 1942. (Formerly NACA ARR, Aug. 1942.)

3. Neihouse, Anshal I., Lichtenstein, Jacob H., and Pepoon, Phillip W.: Tail-Design Requirements for Satisfactory Spin Recovery. NACA TN 1045, 1946.

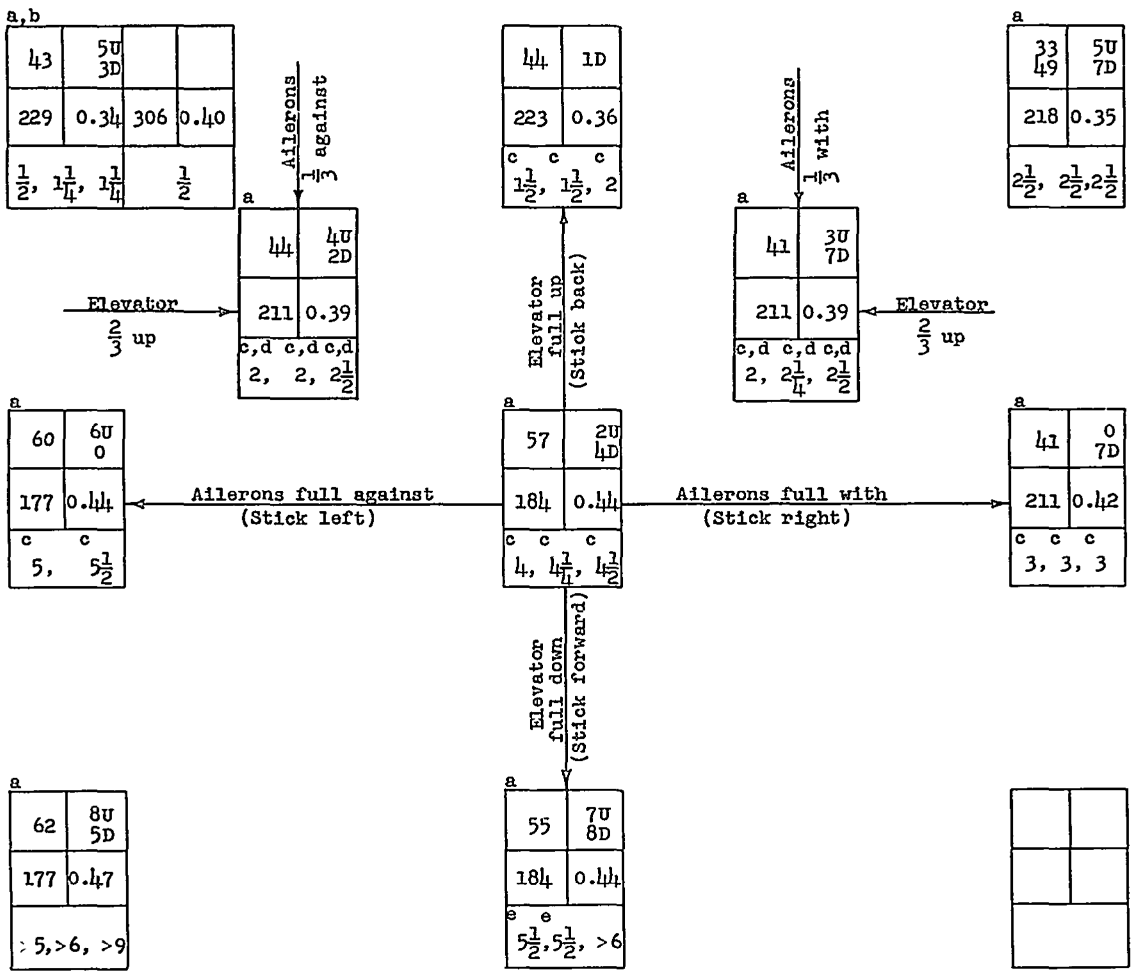
4. Berman, Theodore: Comparison of Model and Full-Scale Spin Test Results for 60 Airplane Designs. NACA TN 2134, 1950.

CHART 1.– SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Direction | Loading (see table II) | |
|---|---|---|---|---|
| T-28C | Erect | Right | Clean condition 100 percent fuel | $\frac{I_X - I_Y}{mb^2} = -60 \times 10^{-4}$ |
| Slats | Flaps | Rudder | Center-of-gravity position | Altitude |
| | | Original | 25 percent $\bar{c}$ | 20,000 ft |

Model values converted to full scale U–inner wing up D–inner wing down




[a]Slightly oscillatory, range of values given.
[b]Two conditions possible.
[c]Model recovered in a dive.
[d]Recovery attempted by reversing rudder to $\frac{2}{3}$ against the spin.
[e]Model recovered in an inverted dive.

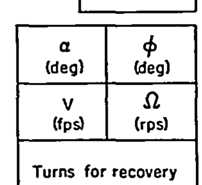
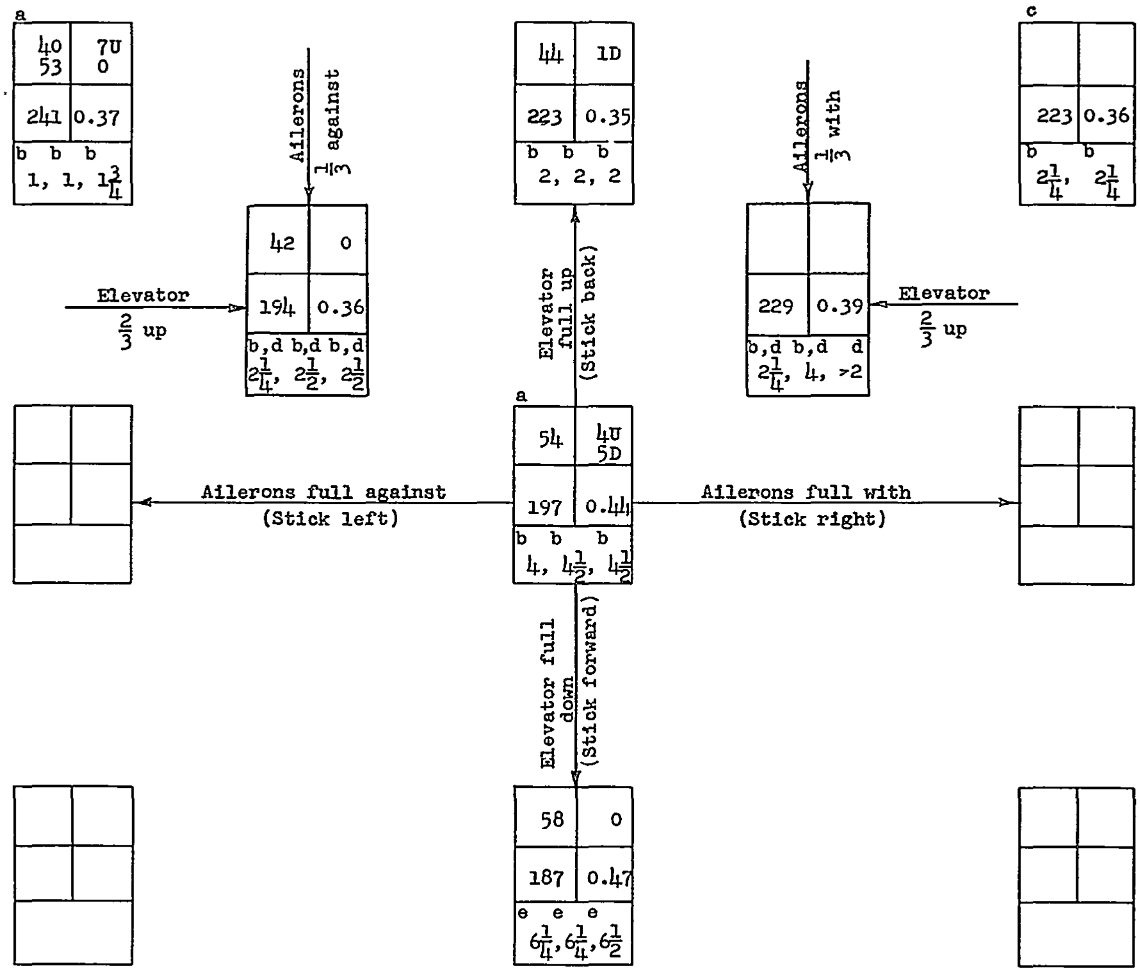


CHART 2.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane T-28C | Attitude Erect | Direction Right | Loading (see table II) Gun package 100 percent fuel | $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ | |
|---|---|---|---|---|---|
| Slats | Flaps | Rudder Original | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft | |

Model values converted to full scale U—inner wing up D—inner wing down




[a]Slightly oscillatory, range of values given.
[b]Model recovered in a dive.
[c]Wandering spin.
[d]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin.
[e]Model recovered in an inverted dive.

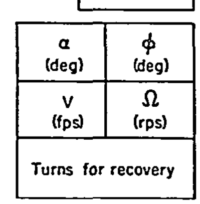
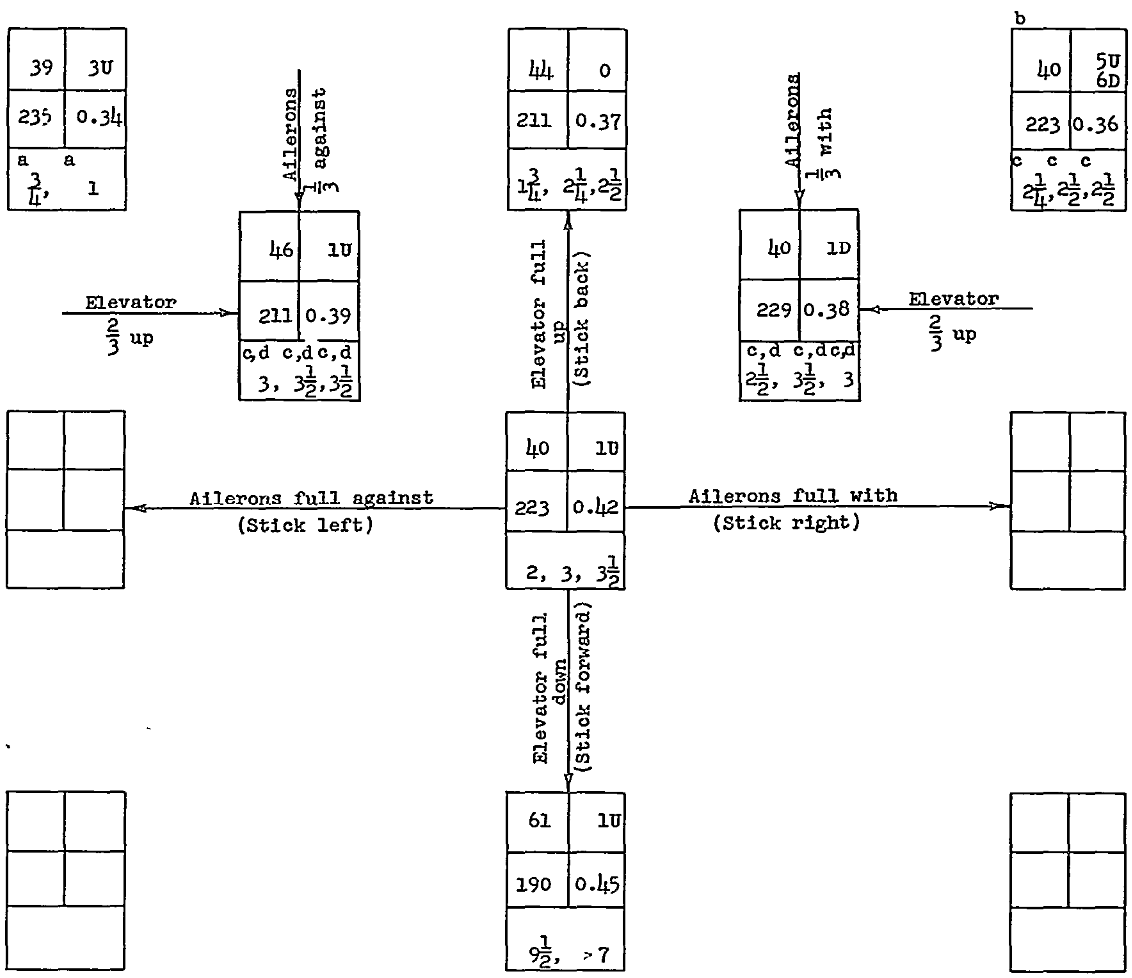


CHART 3.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane T-28C | Attitude Erect | Direction Right | Loading (see table II) Gun package with pylons 100 percent fuel | | $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ |
|---|---|---|---|---|---|
| Slats | Flaps | Rudder Original | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft | |

Model values converted to full scale U–inner wing up D–inner wing down




[a]Model recovered in a dive, then started spinning in opposite direction.
[b]Slightly oscillatory, range of values given.
[c]Model recovered in a dive.
[d]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin.

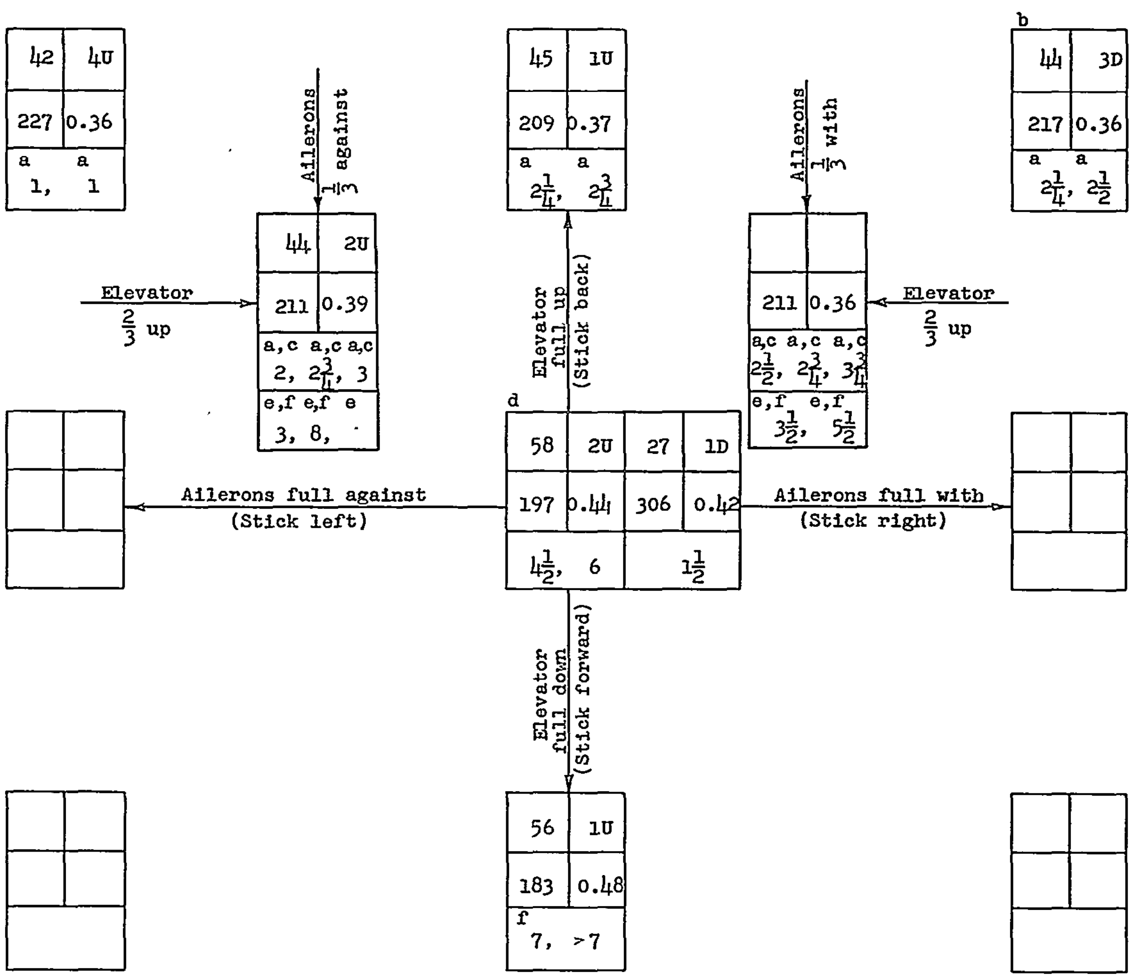
| $\alpha$ (deg) | $\phi$ (deg) |
|---|---|
| V (fps) | $\Omega$ (rps) |
| Turns for recovery | |

CHART 4 .– SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane T-28C | Attitude Erect | Direction Right | Loading (see table II) Gun package replaced with weights 100 percent fuel $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ | |
|---|---|---|---|---|
| Slats | Flaps | Rudder Original | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft |

Model values converted to full scale U–inner wing up D–inner wing down




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

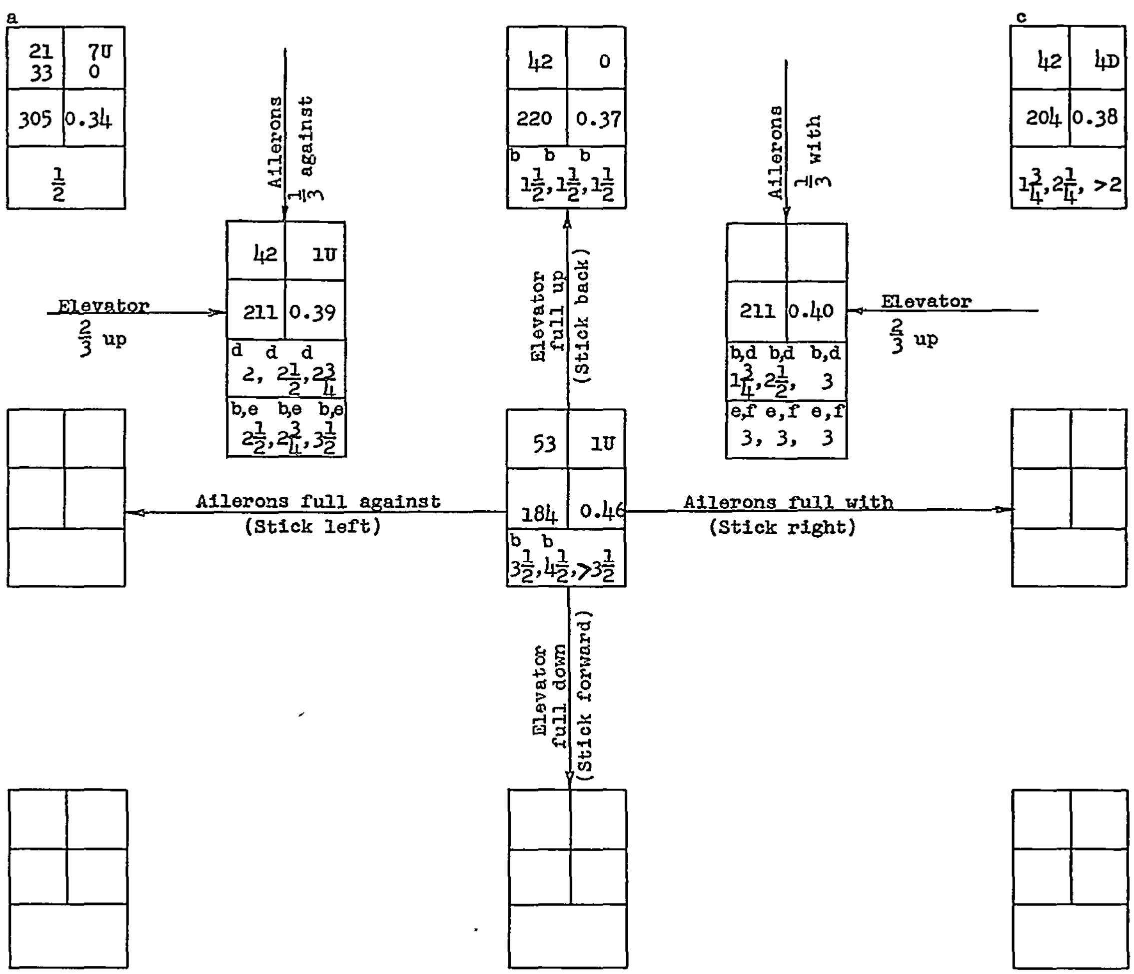
[a]Model recovered in a dive.
[b]Wandering spin.
[c]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin.
[d]Two conditions possible.
[e]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin and simultaneously moving the elevator to $\frac{2}{3}$ down.
[f]Model recovered in an inverted dive.

CHART 5.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Direction | Loading (see table II) | | |
|---|---|---|---|---|---|
| T-28C | Erect | Right | Gun package replaced with weights 100 percent fuel | | $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ |
| Slats | Flaps | Rudder Mark V | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft | |

Model values converted to full scale U–inner wing up D–inner wing down




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

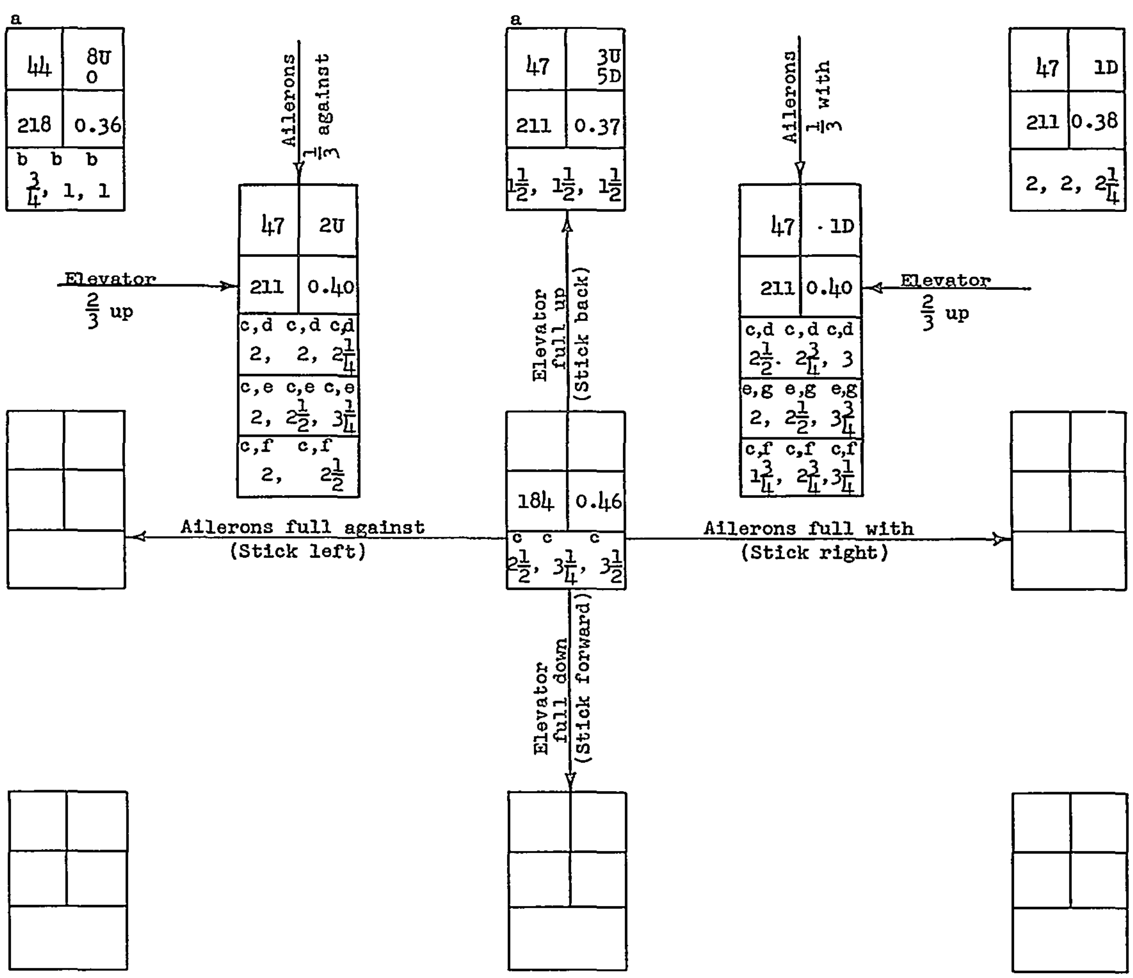
[a]Slightly oscillatory spin, range of values given.
[b]Model recovered in a dive.
[c]Wandering spin.
[d]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin.
[e]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin and simultaneously moving the elevator to $\frac{2}{3}$ down.
[f]Model recovered in an inverted dive.

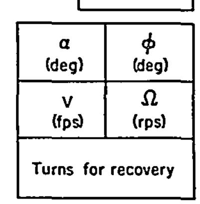
CHART 6 .—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane T-28C | Attitude Erect | Direction Right | Loading (see table II) Gun package replaced with weights 100 percent fuel | | $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ |
|---|---|---|---|---|---|
| Slots | Flaps | Rudder Mark VI | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft | |

Model values converted to full scale U—inner wing up D—inner wing down



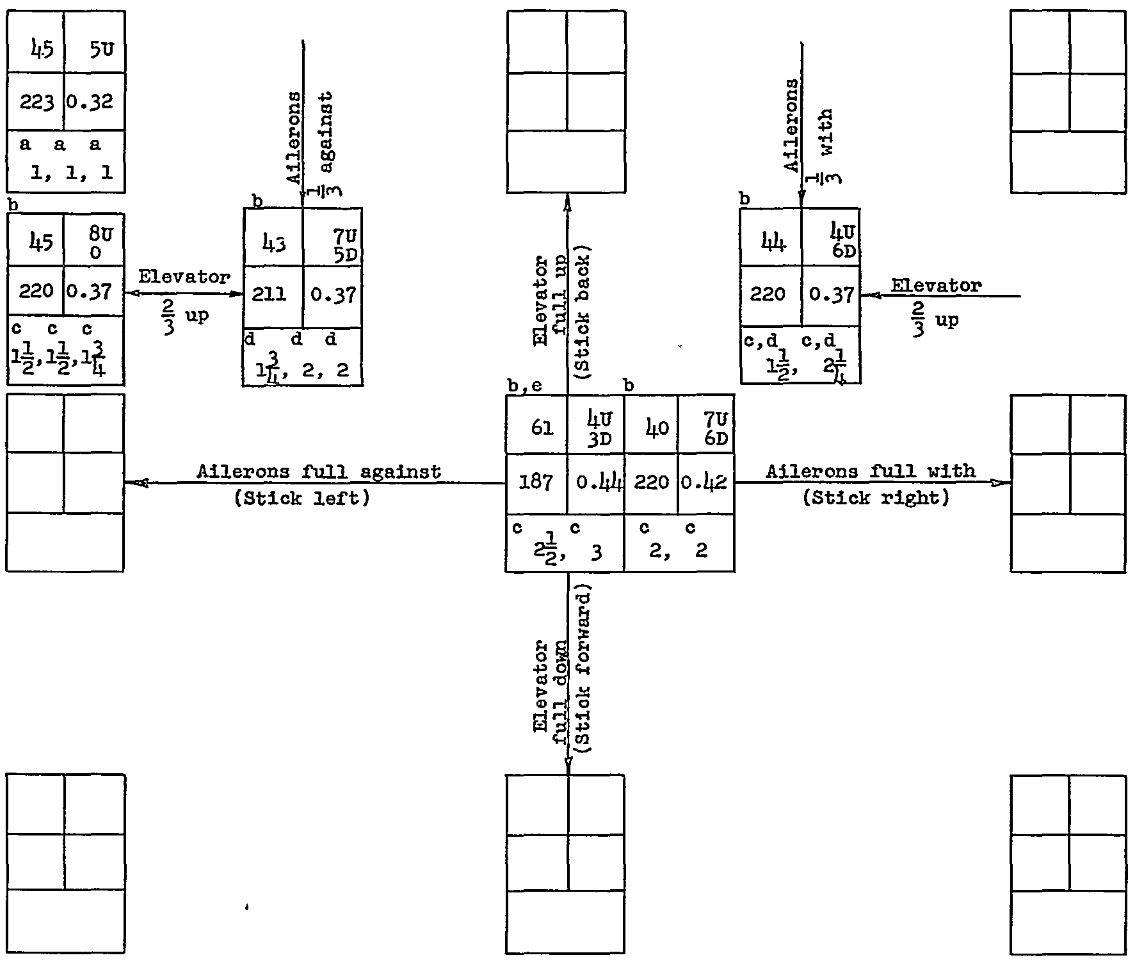

[a]Slightly oscillatory, range of values given.
[b]After recovery, model turned in opposite direction.
[c]Model recovered in a dive.
[d]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin.
[e]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin and simultaneously moving the elevator $\frac{2}{3}$ down.
[f]Recovery attempted by reversing the rudder to $\frac{2}{3}$ against the spin and simultaneously moving the elevator to neutral.
[g]Model recovered in an inverted dive.

CHART 7.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Direction | Loading (see table II) | | |
|---|---|---|---|---|---|
| T-28C | Erect | Right | Gun package replaced with weights 100 percent fuel | | $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ |
| Slots | Flaps | Rudder Mark V | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft | Strake A Position 1 |

Model values converted to full scale    U—inner wing up    D—inner wing down




[a]After recovery, model went into spin in opposite direction.
[b]Slight oscillatory, range of values given.
[c]Model recovered in a dive.
[d]Recovery attempted by reversing the rudder to ⅔ against the spin.
[e]Two conditions possible.

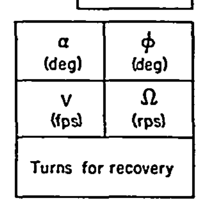
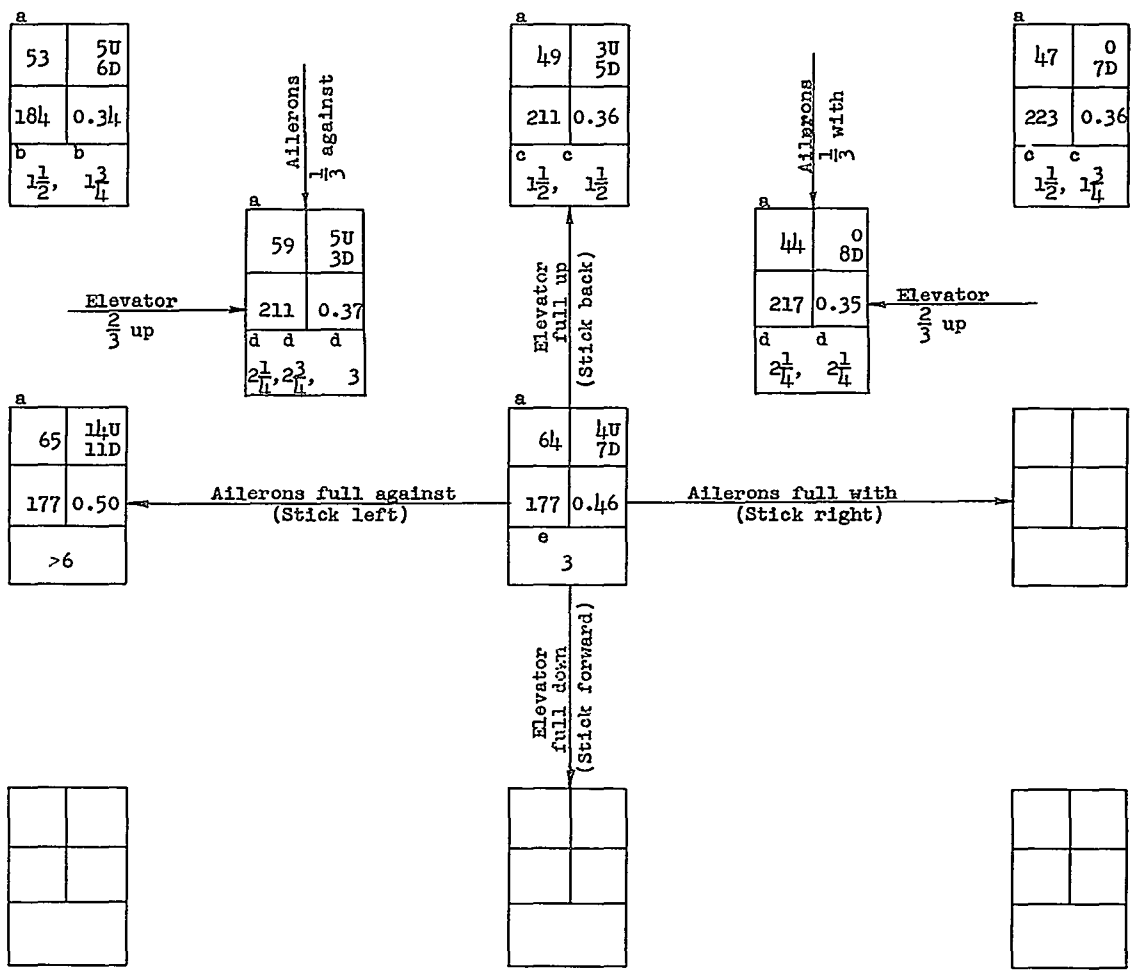


CHART 8.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Direction | Loading (see table II) | | |
|---|---|---|---|---|---|
| T-28C | Erect | Right | Gun package replaced with weights 55 percent fuel | | $\frac{I_X - I_Y}{mb^2} = -99 \times 10^{-4}$ |
| Slots | Flaps | Rudder Mark V | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft | Strake A Position 1 |

Model values converted to full scale U—inner wing up D—inner wing down




[a]Slightly oscillatory, range of values given.
[b]Model recovered in a dive.
[c]Model recovered in a dive, then turned in opposite direction.
[d]Recovery attempted by reversing rudder to $\frac{2}{3}$ against the spin.
[e]Visual estimate.

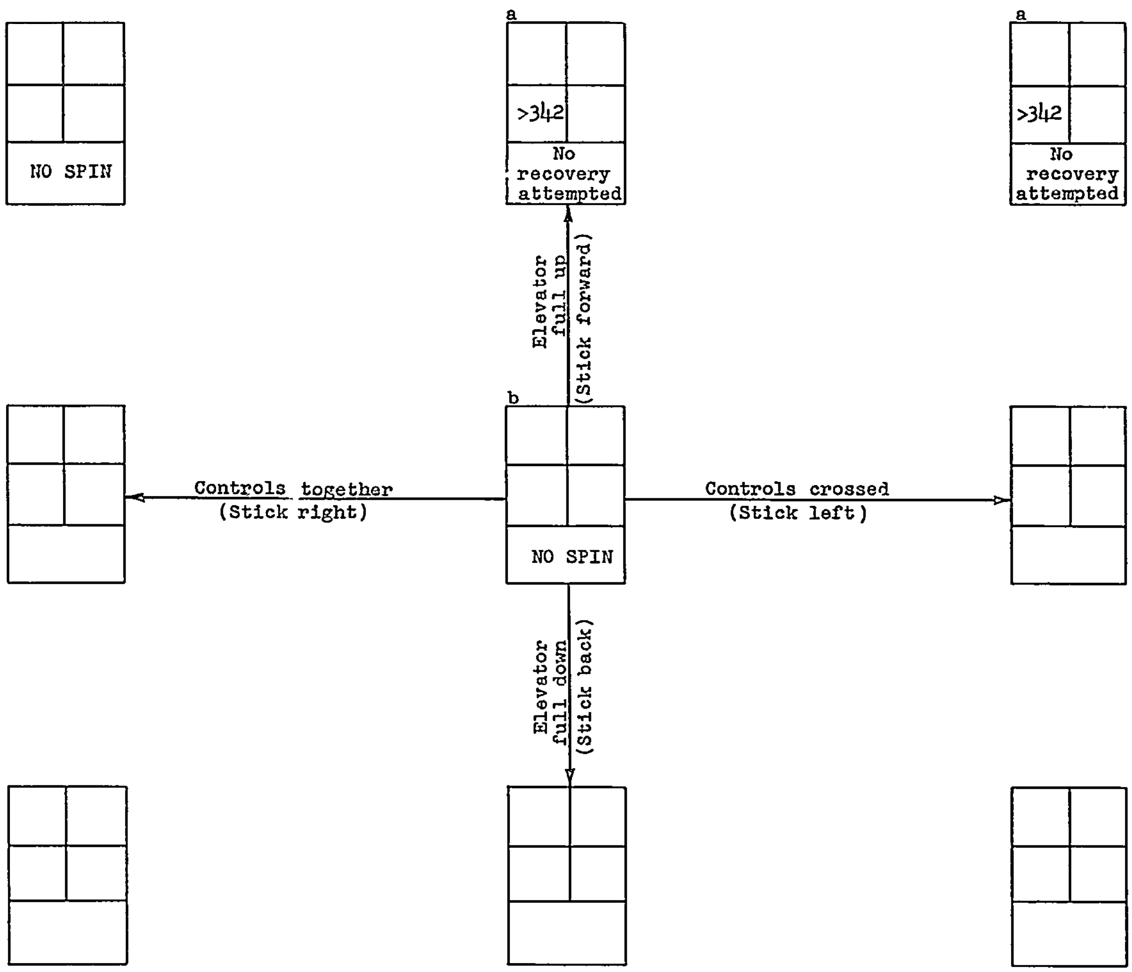
| α (deg) | φ (deg) |
|---|---|
| V (fps) | Ω (rps) |
| Turns for recovery | |

CHART 9.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Direction | Loading (see table II) | | |
|---|---|---|---|---|---|
| T-28C | Inverted | To pilot's right | Gun package replaced with weights 100 percent fuel | | $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ |
| Slots | Flaps | Rudder Original | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft | Strake A, Position 1 |

Model values converted to full scale    U–inner wing up    D–inner wing down




[a]Steep spin.
[b]Model entered a dive.

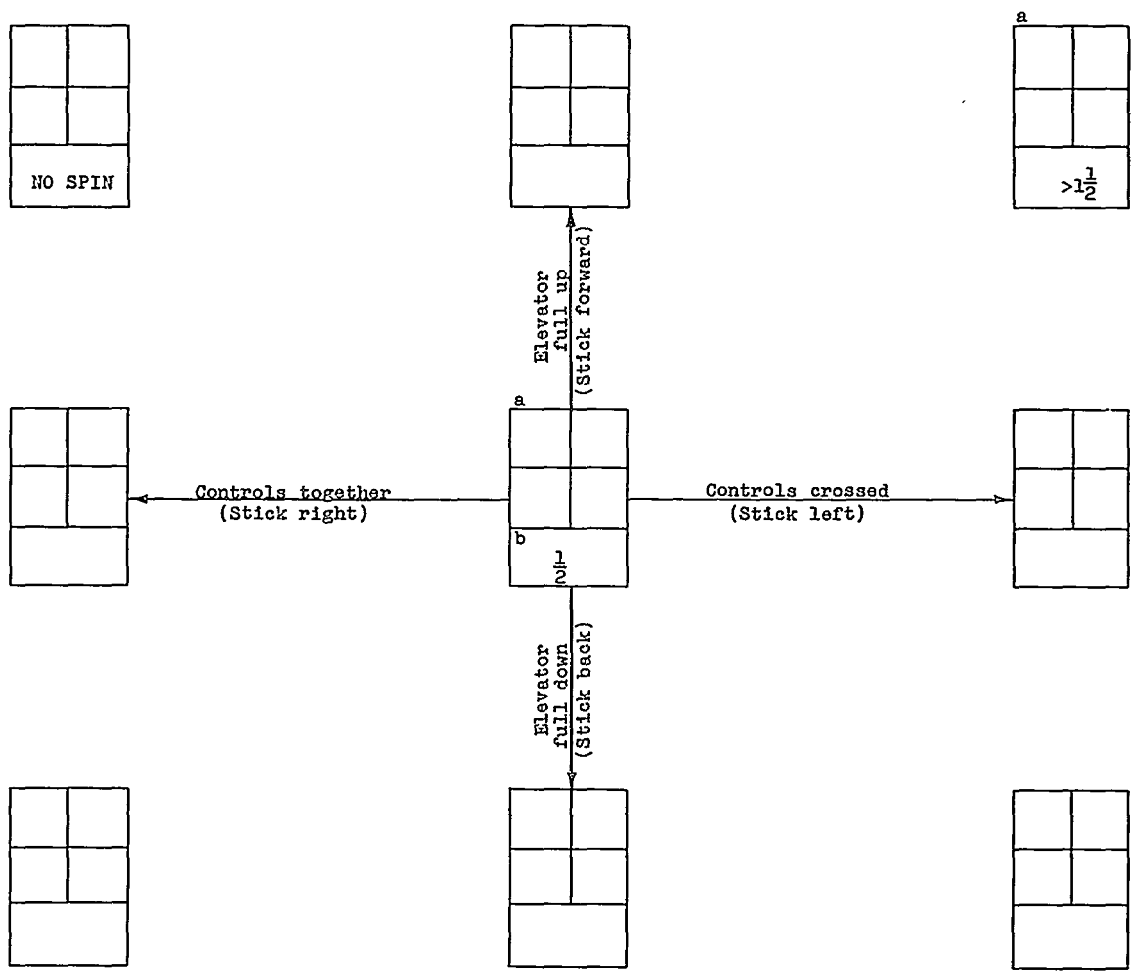
| $\alpha$ (deg) | $\phi$ (deg) |
|---|---|
| V (fps) | $\Omega$ (rps) |
| Turns for recovery | |

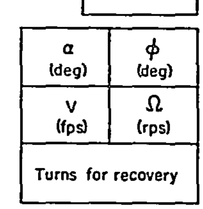
CHART 10.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Direction | Loading (see table II) | |
|---|---|---|---|---|
| T-28C | Inverted | To pilot's right | Gun package replaced with weights 55 percent fuel $\frac{I_X - I_Y}{mb^2} = -99 \times 10^{-4}$ | |
| Slats | Flaps | Rudder Mark V | Center-of-gravity position 25 percent $\bar{c}$ | Altitude 20,000 ft |
| | | | | Strake A, Position 1 |

Model values converted to full scale U–inner wing up D–inner wing down




[a]Steep spin.
[b]Model recovered in a vertical dive.

TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE NORTH AMERICAN T-28C

| | |
|---|---|
| Overall length, ft | 32.77 |
| Wing: | |
| Span, ft | 40.59 |
| Area, sq ft | 271.05 |
| Airfoil section: | |
| Root | Mod. NACA 64A215 (a = 0.8) |
| Tip | Mod. NACA 64A215 (a = 0.8) |
| Mean aerodynamic chord, in. | 81.21 |
| Aspect ratio | 6.08 |
| Taper ratio | 0.62 |
| Dihedral, deg | 8 |
| Incidence: | |
| Root, deg | 2 |
| Tip, deg | -1 |
| Ailerons: | |
| Total area (rearward of hinge line and including tabs), sq ft | 25.82 |
| Horizontal tail: | |
| Total area, sq ft | 58.09 |
| Aspect ratio | 4.61 |
| Total elevator area (rearward of hinge line and including tabs), sq ft | 15.45 |
| Airfoil section: | |
| Root | NACA 64A012 |
| Tip | NACA 64A012 |
| Distance from center of gravity (25 percent $\bar{c}$) to elevator hinge line, ft | 18.72 |
| Vertical tail: | |
| Total area, sq ft | 28.34 |
| Rudder area (rearward hinge line), sq ft: | |
| Original | 10.18 |
| Mark V | 12.67 |
| Mark VI | 14.08 |
| Airfoil section: | |
| Root | NACA 64A012 |
| Tip | NACA 64A012 |
| Distance from center of gravity (25 percent $\bar{c}$) to original rudder hinge line, ft | 20.73 |
| Distance from center of gravity (25 percent $\bar{c}$) to Mark V and VI rudder hinge line, ft | 20.82 |
| Original rudder: | |
| Tail-damping ratio | 0.0287 |
| Unshielded-rudder volume coefficient | 0.0182 |
| Tail-damping power factor | $522 \times 10^{-6}$ |
| Mark V rudder: | |
| Tail-damping ratio | 0.0287 |
| Unshielded-rudder volume coefficient | 0.0258 |
| Tail-damping power factor | $740 \times 10^{-6}$ |
| Mark VI rudder: | |
| Tail-damping ratio | 0.0287 |
| Unshielded-rudder volume coefficient | 0.0328 |
| Tail-damping power factor | $941 \times 10^{-6}$ |

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADINGS POSSIBLE ON THE NORTH AMERICAN T-28C AIRPLANE AND FOR LOADINGS TESTED ON THE MODEL

(Values given are full scale, and moments of inertia are given about the c.g.)

| Loading | Weight, lb | Center-of-gravity location | | Relative density, $\mu$ | | Moments of inertia, slug ft$^2$ | | | Mass parameters | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $x/\bar{c}$ | $z/\bar{c}$ | Sea level | Altitude 20,000 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 | | | | | | | | | | | |
| Clean 100 percent fuel | 8216 | 0.250 | 0.114 | 9.8 | 18.3 | 8736 | 11,202 | 18,783 | $-59 \times 10^{-4}$ | $-180 \times 10^{-4}$ | $239 \times 10^{-4}$ |
| Gun package 100 percent fuel | 8679 | .252 | .114 | 10.3 | 19.3 | 9516 | 11,314 | 19,606 | -40 | -187 | 227 |
| Gun package 55 percent fuel | 8300 | .250 | .114 | 9.9 | 18.5 | 7100 | 11,300 | 17,250 | -99 | -140 | 239 |
| Model values | | | | | | | | | | | |
| Clean 100 percent fuel | 8219 | 0.246 | 0.112 | 9.7 | 18.3 | 8634 | 11,184 | 18,408 | $-61 \times 10^{-4}$ | $-172 \times 10^{-4}$ | $233 \times 10^{-4}$ |
| Gun package 100 percent fuel | 8711 | .255 | .121 | 10.4 | 19.4 | 9525 | 11,477 | 19,571 | -44 | -181 | 225 |
| Gun package 55 percent fuel | 8429 | .242 | .116 | 10.0 | 18.8 | 7152 | 11,522 | 17,326 | -101 | -134 | 235 |

TABLE III.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH VARIOUS MODIFICATIONS

[Recovery attempted by reversing rudder to $\frac{2}{3}$ against the spin (recovery attempted from, and developed-spin data presented for, rudder full with spins); model values converted to full scale]

| Loading | Modifications | Rudder | Control settings: Rudder | Control settings: Ailerons | Control settings: Elevator | α, deg | [a] ϕ, deg | V, fps | Ω, rps | Turns for recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| Gun package 100 percent fuel $\frac{I_X - I_Y}{mb^2} = -40 \times 10^{-4}$ | Strake A Position 1 | Original | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 46 | [b] 5U 6D | 214 | 0.35 | [c]2, [c]$2\frac{1}{2}$, [c]$2\frac{1}{2}$ |
| | | Original | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 44 | [b] 4U 8D | 217 | 0.35 | [c]2, [c]$2\frac{1}{4}$, [c]$2\frac{1}{2}$ |
| | Strake B Position 1 | Original | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 42 | [b] 7U 0 | 223 | 0.36 | [c]$2\frac{1}{4}$, [c]$2\frac{1}{2}$, [c]$2\frac{3}{4}$ |
| | | Original | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 40 | 2D | 231 | 0.37 | [c]2, [c]$2\frac{1}{4}$, $>1\frac{1}{4}$ |
| | Strake C Position 1 | Original | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 43 | 3U | 227 | 0.37 | $2\frac{1}{4}$, $3\frac{1}{2}$, $3\frac{1}{2}$ |
| | Strake D Position 1 | Original | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 43 | [b] 7U 3D | 220 | 0.32 | $3\frac{1}{2}$, >4, ∞ |
| | | Original | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 38 | [b] 5U 4D | 241 | 0.34 | [c]$1\frac{1}{2}$, [c]$1\frac{3}{4}$, [c]2, [c]2, $>1\frac{1}{4}$ |
| | | Mark V | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 44 | [b] 5U 2D | 217 | 0.36 | $1\frac{3}{4}$, $2\frac{1}{2}$, $3\frac{1}{4}$ |
| | Strake A Position 1 | Mark VI | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 46 | [b] 6U 2D | 211 | 0.38 | [c]$1\frac{3}{4}$, [c]2, [c]$2\frac{1}{2}$ |
| | | Mark VI | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 44 | [b] 3U 5D | 220 | 0.37 | [c]$1\frac{1}{4}$, [c]$1\frac{1}{2}$, [c]$1\frac{1}{2}$ |
| | Strake E Position 1 | Mark VI | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 49 | [b] 3U 4D | 211 | 0.39 | [c]$2\frac{1}{4}$, [c]$2\frac{1}{4}$, [c]$2\frac{1}{2}$ |
| | Strake E Position 2 | Mark VI | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 45 | [b] 5U 5D | 211 | 0.39 | [c]2, [c]2, [c]$2\frac{1}{4}$ |
| | Strake E Position 3 | Mark VI | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | -- | -- | 211 | 0.40 | $2\frac{1}{4}$, $2\frac{1}{2}$ |
| | Rudder and elevator deflection increased | Mark V | 30° with | $\frac{1}{3}$ with | 20° up | 48 | 1D | 214 | 0.40 | [c]$2\frac{1}{2}$, [c]$2\frac{1}{2}$, [c]$2\frac{3}{4}$ |
| | Elevator deflection increased | Mark VI | 25° with | $\frac{1}{3}$ with | 20° up | 48 | 1D | 217 | 0.40 | [c]$2\frac{3}{4}$, [c]3, [c]$3\frac{1}{2}$ |
| | Rudder and elevator deflection increased | Mark VI | 30° with | $\frac{1}{3}$ with | 20° up | 49 | 0 | 217 | 0.40 | [c]$2\frac{1}{2}$, [c]$2\frac{1}{2}$, [c]$2\frac{3}{4}$ |
| | Antispin fillet | Mark VI | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 47 | 0 | 211 | 0.41 | [c]$2\frac{3}{4}$, [c]$3\frac{1}{2}$, $>3\frac{1}{4}$ |
| | Ventral fin | Mark VI | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 45 | 1D | 214 | 0.40 | [c]$2\frac{1}{2}$ |
| Gun package 55 percent fuel $\frac{I_X - I_Y}{mb^2} = -99 \times 10^{-4}$ | Strake A Position 1 | Mark VI | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | [d] 66 | [b] 5U 6D | 177 | 0.45 | [e]3, [e]3, [e]3 |
| | | | | | | 48 | [b] 3U 4D | 201 | 0.39 | [e]2 |
| | | Mark VI | 25° with | $\frac{1}{3}$ with | $16\frac{2}{3}°$ up | 57 | [b] 3U 7D | 217 | 0.38 | [e]$1\frac{1}{2}$, [e]$1\frac{1}{2}$, [e]$1\frac{1}{2}$ |
| | Strake B Position 1 | Original | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 64 | 1D | 184 | 0.46 | >5 |
| | | Mark VI | 25° with | $\frac{1}{3}$ against | $16\frac{2}{3}°$ up | 64 | [b] 5U 5D | 184 | 0.45 | [c]3, [c]3 |

[a]U - Inner wing up.
D - Inner wing down.

[b]Slightly oscillatory in roll, range of values given.

[c]Model recovered in a dive.

[d]Two conditions possible.

[e]Model recovered in a dive, then turned in opposite direction.

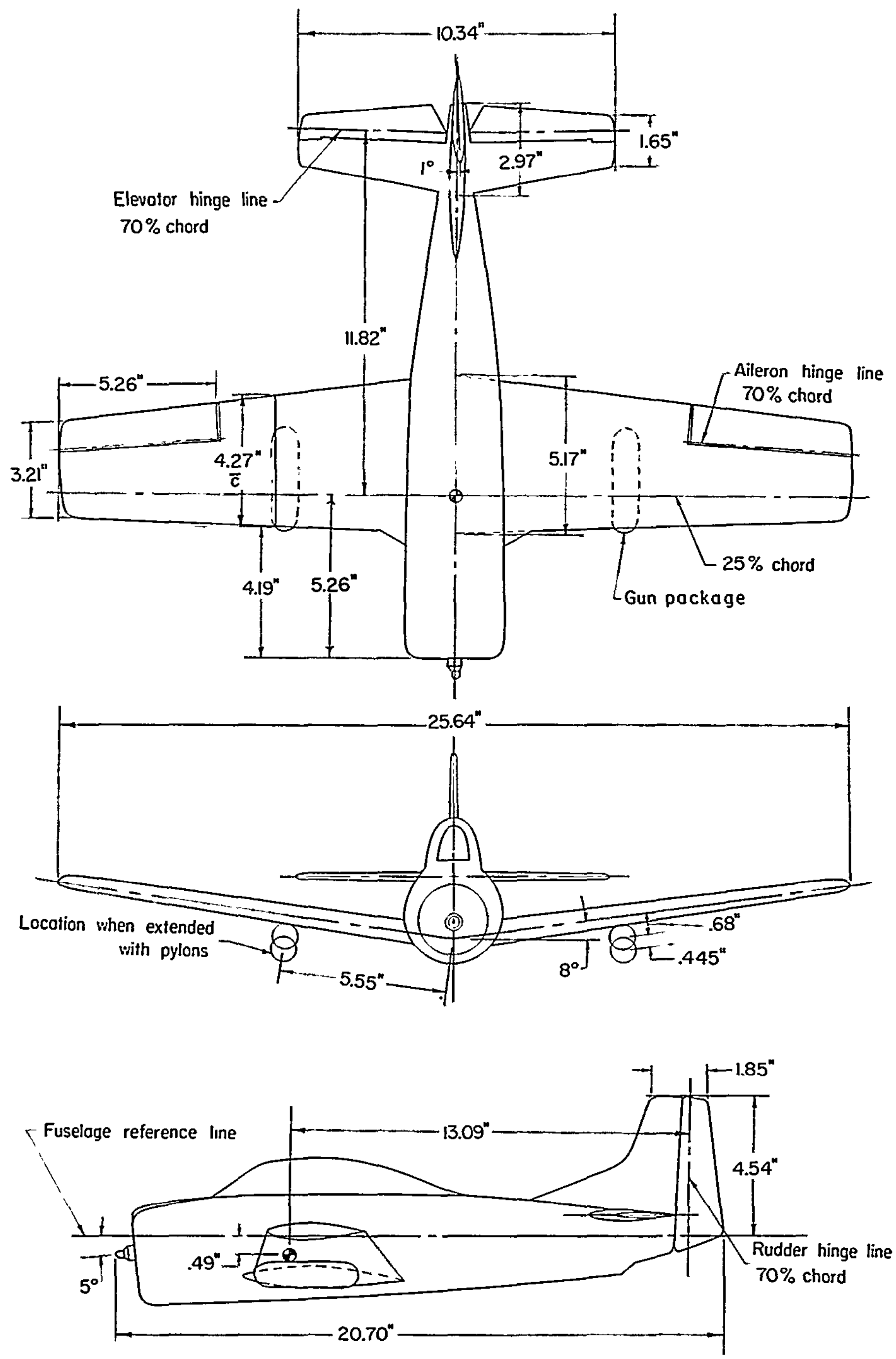



Figure 1.- Three-view drawing of 1/19-scale model of North American T-28C airplane as tested in Langley 20-foot free-spinning tunnel. (Original rudder shown; center of gravity is 25 percent $\bar{c}$; dimensions are in inches.)

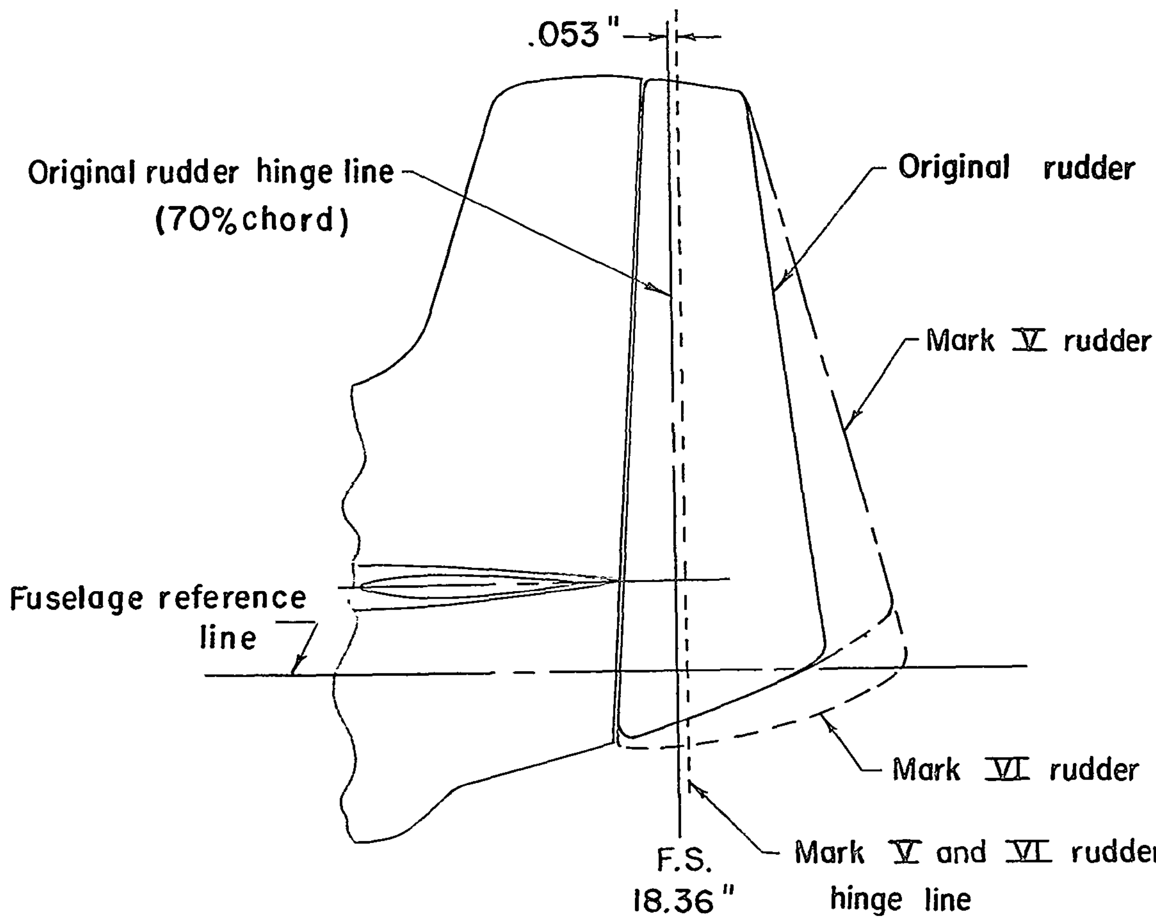



Figure 2.- Three rudders investigated on 1/19-scale model. All dimensions are model scale.

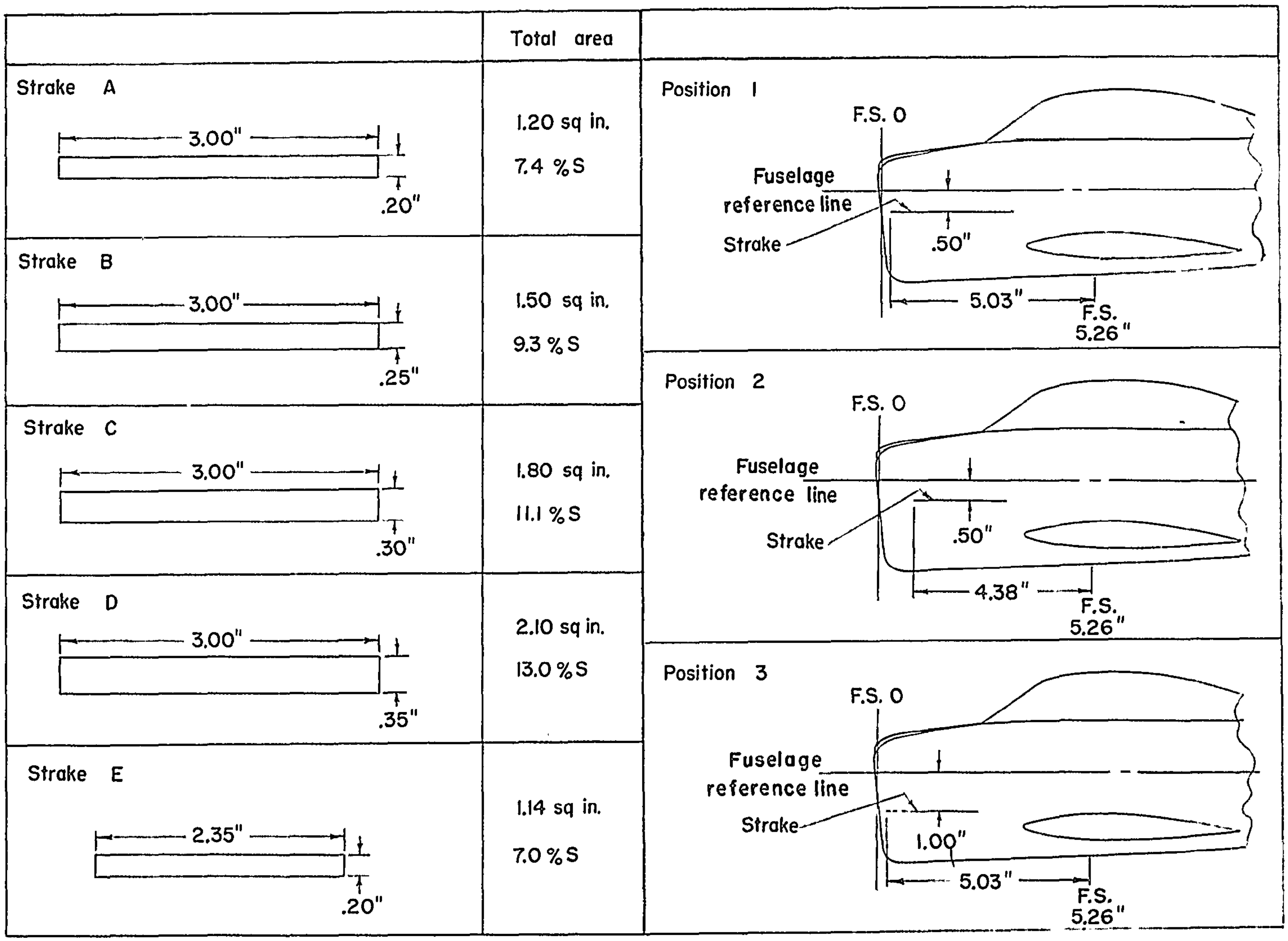
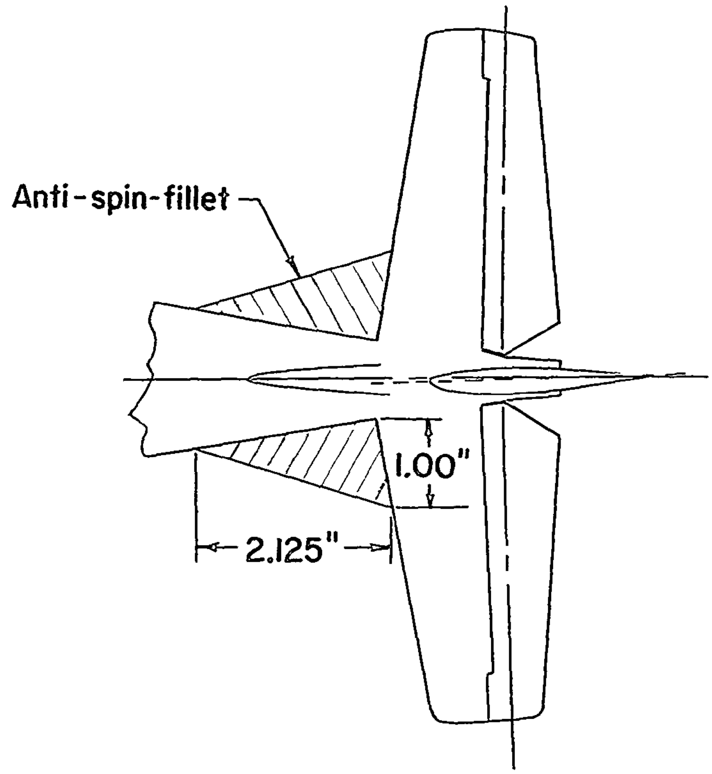
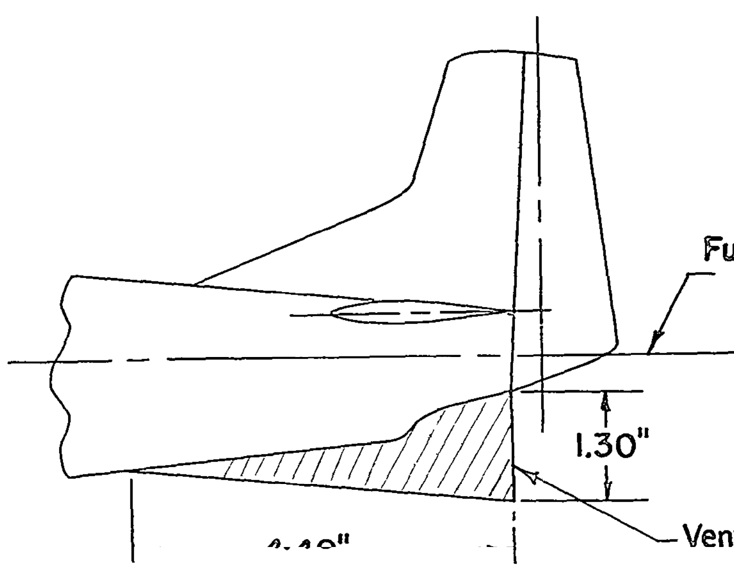



Figure 3.- Location and size of strakes tested on 1/19-scale model of North American T-28c airplane. All dimensions are model scale.


Anti-spin-fillet
1.00"
2.125"


Fuselage reference line
1.30"
Ventral fin

# FREE-SPINNING AND RECOVERY CHARACTERISTICS OF A 1/19-SCALE MODEL OF THE NORTH AMERICAN T-28C AIRPLANE

TED NO. NACA AD 3127

By James S. Bowman, Jr.

## ABSTRACT

An investigation has been conducted in the Langley 20-foot free-spinning tunnel on a 1/19-scale model to determine the spin and recovery characteristics of the North American T-28C airplane. Strakes installed on the nose of the airplane and the use of a larger rudder were found necessary for recovery by full rudder reversal. The optimum control technique for recovery is movement of the rudder to full against the spin with the stick held full back (elevators full up) and ailerons held neutral, followed by forward movement of the stick only after rotation ceases.

## INDEX HEADINGS

| | |
|---|---|
| Airplane - Specific Types | 1.7.1.2 |
| Spinning | 1.8.3 |
| Mass and Gyroscopic Problems | 1.8.6 |
| Piloting Techniques | 7.7 |