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CONTENTS

SUMMARY

An investigation has been conducted in the Langley spin tunnel on a 1/11-scale model of a research airplane which represents a typical low-wing, single-engine, light general aviation airplane. The investigation was made to determine the effects of tail design on spin and recovery characteristics and to evaluate a tail design criterion for satisfactory spin recovery for light airplanes. The effects of other geometric design features on the spin and recovery characteristics were also determined as were the effects of various types of spin-recovery control procedures.

The results indicated that tail configuration can appreciably influence the spin and recovery characteristics of the model tested, as would be expected, but they also indicated that many geometric features other than tail configuration also markedly affected the spin and recovery characteristics. Modifications to the fuselage such as rounding the fuselage bottom or adding ventral fins at the tail were found to be effective in eliminating a flat-spin condition. Also, for the configuration tested, a very sensitive airflow phenomenon existed at the trailing edge of the wing at its juncture with the fuselage with the result that wing fillets, corner modifications, and ventral fins located in that area resulted in dramatic changes in the spin for some tail configurations.

The results also showed that the aileron setting during the spin had a marked effect on spin characteristics such that aileron deflection in the adverse direction could have a strong adverse effect on recovery. The simultaneous use of elevator reversal (from up to down) with rudder reversal did not necessarily aid the spin recovery and in some cases retarded recovery. Also, deflecting the elevator alone for spin recovery was unsuitable, since it was incapable of terminating the developed spin. Investigation of the effects of tail configurations on the spin-recovery characteristics showed that the T-tail and the tail configurations that had the horizontal tail mounted halfway up on the vertical tail produced the best spin recoveries.

The existing tail design criterion for light airplanes, which is based on tail damping power factor (TDPF) as the criterion parameter, did not correctly predict the spin-recovery characteristics of the model. The reasons for the lack of correlation are contained in the aforementioned strong effects of aileron deflection and geometric features other than tail design on spin and recovery characteristics, whereas the criterion considers only the aileron-neutral condition and the geometric characteristics of the tail. These effects are so fundamental that the existing tail design criterion obviously cannot be used to predict recovery characteristics.

INTRODUCTION

Stall/spin accidents have always been a serious safety problem within the general aviation community. Stalling and spinning have been identified as the largest causal factors in fatal general aviation accidents since World War II; and, at the present time, over 28 percent of the total number of general aviation fatal accidents are related to stall/spin (refs. 1 and 2). The spin problem persists mainly because of shortcomings which continue to exist in the areas of pilot training and design guidelines for airplane designers. With regard to airplane design, it is an unfortunate fact that spin research for light general aviation airplanes has been extremely limited and generally neglected for the past 30 years. Previous information published on the spinning characteristics of light airplanes based on spin-tunnel tests at the Langley Research Center is presented in references 3 to 18.

The results of the past research studies and the flight-test experiences of the general aviation manufacturers in this country indicate that the spin characteristics of light airplanes are extremely dependent on many configuration features, to the extent that few generalizations can be made for design purposes. Factors which influence the spin characteristics of light airplanes are quite numerous, and a list of only a few of these factors would include (ref. 17): mass distribution, relative density, wing position, center-of-gravity position, and tail configuration. Because of the large number of variables involved and the lack of research in this area, it is extremely difficult, and perhaps impossible, to predict the spin characteristics of light airplanes prior to flight tests.

One of the few existing design guidelines for spin characteristics was developed for guidance in the design of airplane tail configurations. These guidelines (refs. 18 and 19) involve a tail design parameter, referred to as the tail damping power factor (TDPF), and are based on spin-tunnel tests conducted more than 30 years ago on models of military airplane designs which had values of certain important factors, such as mass distribution, similar to those values exhibited by general aviation airplanes of that era. Although the results of references 18 and 19 were intended to serve only as conservative guidelines for providing a satisfactory tail design for spinning, the references do not clearly state that the results should be used as guidelines rather than criteria. Over the past 30 years, the data have been frequently misinterpreted, misused, and extrapolated to conditions for which they were not intended. For example, the guidelines have been used in attempts to predict quantitatively the spin characteristics of the total airplane configuration. Because configuration features other than the tail can have an overpowering influence, many "erroneous" predictions of spin characteristics by the tail design guidelines have been reported.

In recognition of the need to document the proper application and usefulness of the tail design criteria and to develop more useful design guidelines for prediction of spin characteristics, the NASA Langley Research Center initiated a broad stall/spin research program in recent years involving spin-tunnel tests, radio-controlled model tests, and full-scale flight tests for a number of configurations, including low-wing, high-wing, and twin-engine designs. Each of the configurations to be tested is representative of typical general aviation airplanes weighing under 18 000 N (4000 lb). The program involves a wide range of test variables, such as tail configuration, wing airfoil and planform, fuselage cross-sectional shape, center-of-gravity position, and parachute size for emergency spin recovery.

The present investigation was conducted in the Langley spin tunnel with the first of a series of models of representative single-engine general aviation airplanes to determine the effects of tail configuration on spin characteristics. The model, a low-wing design, was tested with nine tail configurations in addition to ventral fins and fuselage modifications. The validity of applying the existing tail design criterion (ref. 18) for predicting spin characteristics was evaluated. Various spin-recovery control procedures were also evaluated.

SYMBOLS

In order to facilitate usage of data presented, dimensional quantities are presented both in the International System of Units (SI) and in the U.S. Customary Units. Measurements were made in the U.S. Customary Units, and equivalent dimensions were determined by using the conversion factors given in reference 20.

b — wing span, m (ft)

$\bar{c}$ — mean aerodynamic chord, cm (in.)

I_X, I_Y, I_Z — moment of inertia about X, Y, and Z body axis, respectively, kg-m^2 (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

L — distance from center of gravity of airplane to centroid of fuselage area S_F, m (ft) (see fig. 18)

L_1 — distance from center of gravity of airplane to centroid of rudder area S_{R1}, m (ft) (see fig. 18)

L_2 — distance from center of gravity of airplane to centroid of rudder area S_{R2}, m (ft) (see fig. 18)

m — mass of airplane, kg (slugs)

R — radius, cm (in.)

S — wing area, m^2 (ft^2)

S_F — fuselage side area under horizontal tail, m^2 (ft^2)

S_{R1} unshielded rudder area above horizontal tail, m^2 (ft^2)

S_{R2} unshielded rudder area below horizontal tail, m^2 (ft^2)

TDPF tail damping power factor

TDR tail damping ratio

URVC unshielded rudder volume coefficient

V full-scale rate of descent, m/sec (ft/sec)

x distance of center of gravity rearward of leading edge of mean aerodynamic chord, m (ft)

z distance between center of gravity and fuselage reference line (positive when center of gravity is below line), m (ft)

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

δ_a aileron deflection angle, deg

δ_e elevator deflection angle, deg

δ_r rudder deflection angle, deg

μ airplane relative-density coefficient, $m/\rho Sb$

ρ air density, kg/m^3 ($slugs/ft^3$)

ϕ angle between span axis of wing and horizontal, deg

Ω angular velocity about spin axis, rps

METHOD OF APPROACH

The approach used in the present investigation consisted of spin-tunnel tests of a representative low-wing model for a large number of tail configurations. The tail configuration was varied by a systematic relocation of the horizontal tail in both the vertical and the horizontal direction; use of both full-span and partial-span rudders; and the use of ventral fins.

The spin characteristics exhibited by the model were compared with the results predicted by the existing tail design criterion for light airplanes (ref. 18). Also, results obtained from the tests of the various tail designs were compared in order to determine the relative effectiveness for spin recovery of each tail design. The effects of design features other than tail design on spin and spin-recovery characteristics were also evaluated. For example, the effects of strakes, changes to the fuselage cross-sectional shape, and changes to the wing-fuselage fillet were investigated.

TAIL DAMPING POWER FACTOR CRITERION

Historical Development

Early research.- The British Royal Aircraft Establishment (R.A.E.) conducted the first analysis of test results for spin-tunnel models (ref. 21, 1937) in an attempt to establish a criterion which would indicate whether a design had a "reasonable chance" of passing the spinning requirements. These requirements stated that the model must recover by rudder reversal within 8 sec (full-scale time) from the time the rudder was moved. The 8-sec time requirement is estimated to be equivalent to about 2 to 3 turns for recovery, depending on the spin rate of the model at the time recovery is attempted. This criterion was required to be met at the most critical mass- and center-of-gravity loading condition.

In developing the R.A.E. criterion, three design factors were considered to have a major effect on the spinning characteristics of an airplane (power was not simulated):

(1) The longitudinal distribution of mass, as measured by the difference in I_Z and I_X expressed nondimensionally as $(I_Z - I_X)/\rho S(b/2)^3$

(2) The resistance offered by the fuselage side area while the airplane was spinning (rudder area excluded)

The fuselage areas both ahead of and behind the center of gravity were considered to contribute to spin damping. Because of its presumed greater effectiveness, the area beneath the horizontal tail was multiplied by a factor of 2. The damping parameter was expressed as $\Sigma Ax^2/S(b/2)\rho$, where A is an elementary area located at a distance x from the center of gravity of the airplane. When summed for the total configuration, this parameter was termed the body damping ratio (BDR).

(3) The unshielded rudder area, expressed as an unshielded rudder volume coefficient (URVC)

The URVC is equal to the product of the rudder area not immersed in the estimated wake of the horizontal tail and the distance from the centroid of the unshielded rudder area to the airplane center of gravity divided by the product of wing area and wing semispan.

The BDR and URVC were multiplied together to produce a "damping power factor" (DPF), which was plotted against the inertia term $(I_Z - I_X)/\rho S(b/2)^3$ for each model. If the model failed to pass the 8-sec time requirement for recovery, the model was plotted as "fail," and if it did pass, it was plotted as "pass." A boundary line was drawn to separate the pass and fail points such that all points below the boundary were fail, but there were both pass and fail points above the boundary. The criterion was referred to as minimum requirements of the model design before spin-tunnel tests could be conducted. The main objective of the criterion, therefore, was to serve as a guideline to indicate whether a model design had a reasonable chance of having good spin characteristics. It was pointed out that the use of DPF alone was not adequate to predict the spin-recovery characteristics of the model, since many secondary factors were not included in the analysis. Therefore, no guarantee was given that the design would exhibit satisfactory spin-recovery characteristics without actual model tests.

Modification by NACA.- When the R.A.E. criterion was applied to some United States airplane designs, it was found that the separation between the "good spinners" (good recoveries) and the "poor spinners" (poor recoveries) was not very good, and a study was initiated to improve the criterion (ref. 22, 1939). The primary change made to the R.A.E. criterion was the manner in which the fuselage damping was computed and used. A new term, called tail damping ratio (TDR), which considered only the body and/or vertical-tail area (excluding the rudder) beneath the horizontal tail, replaced the body damping ratio term. Since URVC was thought to be just as important as TDR in effecting a separation between the good and poor spinner, it was decided to use the product of these two terms as a criterion of merit. This product was called the tail damping power factor (TDPF). By using this approach and plotting TDPF against $(I_Z - I_X)/\rho S(b/2)^3$, 14 United States monoplane designs that were tested in the spin tunnel were separated into good and poor spinners, as determined by spin-tunnel tests. On the basis of the results of these 14 airplane designs, it was concluded that a TDPF of at least 150×10^{-6} would be needed for satisfactory spin recovery. It was pointed out that even though the TDPF was considered an important factor in tail design, other factors, such as the wing, could have important effects on the spin and spin recovery; therefore, the TDPF could not be considered a complete criterion for spin recovery.

Second modification by NACA.- A few years later, after a considerable amount of model testing by NACA in the Langley spin tunnel, the TDPF criterion was modified again to include the results of about 100 military airplane designs (ref. 19, 1946). These airplanes included biplanes and low-wing monoplanes; no high-wing designs were used in the analysis. As a result of this investigation, several changes were made in the previous TDPF criterion. First, it was found that the relative distribution of the mass along the wing and the fuselage and the density coefficient μ of the airplane relative to the air had significant influence on the relative effectiveness of the rudder and elevators for spin recovery. Therefore, the use of μ was introduced as a parameter to draw the boundary for satisfactory or unsatisfactory recoveries. Also, it was found that deflection of the ailerons could make the spin recovery more difficult.

Second, the method of computing the TDPF was changed. For the models with partial-span rudders, an analysis of the 100 designs indicated that the TDR had an influence on the model spin attitude. For values of TDR greater than 0.019, most of the models spun at an average angle of attack of about 30°; for values of TDR less than 0.019, the average angle of attack was closer to 45°. The value of the TDR was therefore used as a guide to estimate the spin angle of attack for designs with partial-span rudders. For full-span rudder designs, the angle of attack of the model was assumed to be 30°. For more detailed information on computing the tail damping power factor, see appendix A.

Third, the value of TDPF was plotted against the inertia yawing-moment parameter $(I_X - I_Y)/mb^2$ rather than a parameter related to the inertia pitching moment $(I_Z - I_X)/\rho S(b/2)^3$. It was believed that since the spin is primarily a yawing motion, the study of the spin should be referred to the yawing-moment parameter rather than to the pitching-moment parameter.

Fourth, the method of determining poor to good spinners was changed. Instead of a time limit of 8 sec (full scale) for recovery, the recovery was measured in terms of the number of turns from the time the recovery controls were applied to the time the model stopped spinning. The recovery was considered satisfactory if the model stopped spinning within 2 turns after the controls were applied for recovery from the aileron-neutral condition.

Because it is sometimes difficult for pilots to maintain specific control deflections during a spin, model tests were performed to evaluate the possible adverse effects on recovery of small deviations in the desired control settings. For these tests, the ailerons were deflected one-third of full deflection in the most critical direction, the elevator was deflected only two-thirds full up, and the rudder was moved to only two-thirds of full deflection for recovery. This control configuration and recovery technique is referred to as the criterion spin. Recoveries are satisfactory if accomplished within $2\frac{1}{4}$ turns.

Application to light general aviation airplanes.- The only criterion that has been developed specifically for general aviation airplanes is presented in reference 18 (1947). It was developed from 60 of the 100 various military-type airplane designs discussed in reference 19. The same procedure was used to develop boundaries for satisfactory spin recoveries for airplanes which were considered to be similar to personal-owner-type light airplanes of that era. The TDPF criterion for light airplanes was developed for the aileron-neutral condition only. The criterion boundaries were drawn such that only data points which represented satisfactory recoveries fell above the boundary and both satisfactory and unsatisfactory recoveries fell below the boundary. The recovery characteristics were considered satisfactory if the model recovered in $2\frac{1}{4}$ turns or less by rudder reversal or simultaneous rudder and elevator reversal for all prospin elevator settings when the ailerons were neutral.

Present Status

The only existing tail design criterion for light general aviation airplanes, that of reference 18, is for only the aileron-neutral condition and is presented in figure 1. Boundaries are presented for satisfactory spin recovery for airplanes which have relative-density coefficients μ of 6 and 10 and for a range of inertia yawing-moment parameters $(I_X - I_Y)/mb^2$ from -120×10^{-4} to 120×10^{-4}. It is important to note that the boundaries shown in figure 1 were drawn in a conservative sense on the basis of the model data available at that time. In particular, the boundaries were drawn such that no unsatisfactory spin characteristics were exhibited by models having values of TDPF above the boundaries; however, many designs with satisfactory spin characteristics fell below the boundaries. The fact that airplanes with values of TDPF below the boundaries can exhibit entirely satisfactory spin characteristics is generally not well known or appreciated today.

From experience gained since the criterion was published, it is obvious that factors other than tail design can have very significant effects on spins. In particular, aileron deflection, center-of-gravity position, wing position, tail length, and fuselage shape can produce markedly different spin characteristics for a given tail design. Therefore, it is obvious that the TDPF criterion cannot be used as a criterion for prediction of spin recovery. At best it should be considered only as a guideline for tail design. For example, a large portion of the rudder should be unshielded in order to have an effective rudder to oppose the prospin yawing moment in the spin and thereby provide yawing moment for recovery. Also, it is obvious that the spin damping provided by the area under the horizontal tail can be beneficial in preventing flat spin modes or, in some cases, can cause steep spin modes from which recovery is more easily obtained.

MODEL

A 1/11-scale model of a research airplane which was considered to be a typical low-wing, single-engine, light general aviation airplane was used. A three-view drawing and a photograph of the model are shown in figures 2 and 3, respectively. The basic dimensional characteristics of the model are presented in terms of the corresponding full-scale airplane values in table I. The tail assembly of the model was removable, and independent tail configurations were constructed to permit tests of the nine tail configurations shown in figure 4.

Tails 1, 2, 7, and 9 used partial-span rudders; and the results obtained can be compared to determine the effects of moving the horizontal tail from a low position on the fuselage (tail 1) to higher positions on the vertical tail. Similar comparisons can be made for tails 3, 5, 6, and 8, which used full-span rudders. Other comparisons which can be made include the effect of full- and partial-span rudders and the effect of longitudinal position of the horizontal tail (tails 1 and 4). The largest part of the investigation was conducted with tail configuration 3, which was considered to be most representative of current configurations.

The tail configurations used in the investigation were designed to provide a wide range of values of tail damping power factor (from 45×10^{-6} to 1510×10^{-6}). The tail damping power factor (TDPF), tail damping ratio (TDR), and unshielded rudder volume coefficient (URVC) for each of the tail configurations are presented in table II.

Ventral fins are sometimes used in an attempt to improve the spin and recovery characteristics of an airplane by providing increased damping, which should cause the airplane to spin steeper. Therefore, ventral fins were tested in the present investigation to determine their effect on the spin and recovery characteristics. In calculating the TDPF values of the tails equipped with ventral fins, the additional TDR value provided by the ventral fin was added to the TDR value of the tail configuration alone. Regardless of the length of the ventral fin, only the area of the ventral fin below the horizontal tail was used in calculating the TDR value for the ventral fin. Sketches and dimensions of the ventral fins and their locations for full- and partial-span rudders are shown in figures 5 and 6. The end of the ventral fin is located at the end of the fuselage in both cases. The values of the TDPF for the tail configurations with and without ventral fins are presented in table II.

The cross-sectional shape of the aft fuselage was modified for some tests in the following manner: (1) a rounded "bathtub" section was added to the fuselage bottom, (2) semicircular cylinders were added to each side on the fuselage bottom, (3) fins were added to each side of the fuselage bottom, and (4) strakes were added along the sides of the fuselage. These modifications are described in more detail later in "Results of Tests."

A radio-control system was used to actuate a servomechanism installed in the model to move the control surfaces. Sufficient torque was applied to the controls to move them fully and rapidly to the desired positions. Initial tests with landing gear installed on the model indicated a negligible effect on the spin and recovery characteristics, which is in agreement with results presented in reference 8; therefore, the gear was removed for the major part of the test program. The aerodynamic and gyroscopic effects of propeller operation were not simulated on the model and no power effects were simulated.

TEST CONDITIONS

The tests were performed in the Langley spin tunnel. Reference 23 describes the spin tunnel and the test technique. A summary of the technique is given in appendix B of the present report for the convenience of the reader. The technique involves hand launching the model into a vertical airstream in both flat and steep attitudes with various rates of rotation, since there may be several spin modes possible for a particular configuration and loading. The model is then allowed to enter an equilibrium condition prior to attempting a recovery. A photograph of the present model being tested in the Langley spin tunnel is shown in figure 7.

The model was ballasted to obtain dynamic similarity at an altitude of 3000 m (10 000 ft) with a value of relative-density coefficient μ of 11.0. The mass characteristics and mass parameters for the loading conditions tested on the model have been converted to corresponding full-scale values and are presented in table III. The value of the inertia yawing-moment parameter $(I_X - I_Y)/mb^2$ for the present tests was -50×10^{-4}. The tests were conducted with the center of gravity at $0.145\bar{c}$ and $0.255\bar{c}$. The precision of the measurements of the spin characteristics is given in appendix B.

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

Rudder deflection, deg	25 right, 25 left
Elevator deflection, deg	25 up, 15 down
Aileron deflection, deg	25 up, 20 down

The values of the TDPF for the nine tails tested are located on the tail design criterion chart for a value of μ of 11.0 in figure 8. The boundaries in figure 8 were generated from figure 1 by extrapolation. As shown in figure 8, values for tail designs 5 to 9 are located in the satisfactory region for recovery by only rudder reversal; values for tails 2 and 3 are relatively close to the boundary; and values for tails 1 and 4 are below the boundary into a region where recovery by rudder reversal may be satisfactory or unsatisfactory. The criterion would also predict that all tails, with the exception of tails 1 and 4, would have satisfactory recoveries by simultaneous reversal of rudder and elevator.

To determine the relative effectiveness of the controls and of various control combinations, spin recoveries generally were attempted by rudder reversal alone or in combination with movement of the elevator down. In some instances the rudder and elevator were only neutralized. The ailerons were not moved during recovery.

The normal recommended spin-recovery procedure for light airplanes is to first reverse the rudder and then about 1/2 turn later to move the stick forward. This delayed elevator moment cannot be implemented on the small spin-tunnel models; therefore, in the spin tunnel, simultaneous movements of the controls are used. This technique usually leads to slower recoveries than would be expected if the rudder input preceded the elevator input.

Ailerons have not normally been used for spin recovery, even though some test data indicate that the movement of ailerons could aid recovery. This situation is caused by the fact that the direction in which ailerons are favorable for spin recovery can change from one airplane design to the next and that the use of ailerons in the incorrect direction could prevent recovery altogether. As a result of these considerations, the use of ailerons to aid spin recovery has not been previously recommended, and this technique was not used in the present investigation.

RESULTS OF TESTS

Presentation of Results

The results of the model spin tests to determine the effects of controls and ventral fins on the spin modes are presented in charts 1 to 9. For convenience, the chart number corresponds to the tail configuration number. For example, charts 1(a), 1(b), and 1(c) all refer to tail 1. The effects of fuselage modifications are presented in figure 9.

A sample of the spin data chart used to present spin-tunnel test results is shown in figure 10 to illustrate how the various control positions are represented in the data charts. As illustrated, the results for elevator up (stick back) are presented at the top of the chart; for elevator down (stick forward), at the bottom of the chart. Results for ailerons with the spin (stick right in a right spin) are presented on the right side of the chart; for ailerons against the spin (stick left in a right spin), on the left side of the chart.

On the auxiliary charts, where "Spin block" is a column heading, this block represents a symbol of a spin chart to show at a glance the positions of the elevator and ailerons for the developed spin for a given test. The dot indicates the control positions on the chart for the spin and the arrow indicates the position to which the elevator and ailerons were moved for the recovery attempt. The rudder is always with the spin initially and is always moved to full against the spin for recovery unless otherwise noted.

A summary of the results obtained for the basic tail configurations for the normal and criterion spin control settings is presented in figure 11.

The terminology normally used in describing various types of developed spin modes usually refers to the angle of attack of the airplane during the spinning motion. Since considerable confusion sometimes exists over the definitions of "steep" and "flat" spins, the following guidelines are used to define classical spin modes that have been observed on spinning airplanes:

Spin mode	Angle-of-attack range, deg
Flat	65 to 90
Moderately flat	45 to 65
Moderately steep	30 to 45
Steep	20 to 30

The range of angles of attack shown is not meant to imply that the airplane will oscillate within these values, but that the spin is assumed to be in a steady state and the angle of attack would stay at some approximately constant value within this range. For example, an airplane spinning smoothly at 75° angle of attack would be considered to have a flat spin mode.

The model data are presented in terms of full-scale values for the airplane spinning at an altitude of 3000 m (10 000 ft) with no power effects simulated. Inasmuch as the results for right and left spins are generally similar, all data are presented arbitrarily in terms of right spins.

Interpretation of Results

Specific results of spin-tunnel tests should not be applied directly to corresponding full-scale conditions without proper interpretation. It is necessary to evaluate the spin-tunnel data with a background knowledge of previous spin programs for which spin-tunnel and full-scale results have been correlated. Thus, spin-tunnel model results are not interpreted rigidly for a specific control setting, mass loading, or dimensional configuration. Instead, they are interpreted in terms of a range of results obtained for the combination of mass characteristics, dimensional characteristics, and control settings under investigation by determining the extent to which moderate variations in these factors can alter the results.

Past experience with model tests in the spin tunnel have indicated that good agreement has been obtained with results of full-scale tests most of the time, despite the low Reynolds number of the model tests. The effects of Reynolds number for the current tests are not known at the present time; however, full-scale flight tests and wind-tunnel force tests are planned to evaluate possible Reynolds number effects under both static and rotary conditions.

It is important to note that the use of the terminology "satisfactory spin recovery" in the present study differs from the spin requirements for the acrobatic category that are used in the Federal Aviation Regulations for light airplanes (ref. 24, Sec. 23.221). The term "satisfactory" as used herein indicates that the corresponding airplane should recover from a fully developed spin in a reasonable number of turns. The term "unsatisfactory" as used herein refers to a condition in which the number of turns and/or altitude loss for spin recovery is considered to be excessive or that the airplane may not recover from the spin at all. On the other hand, the requirements in the regulations are quite explicit: recovery must be completed within $1\frac{1}{2}$ turns from a 6-turn spin for acrobatic airplanes after normal application of recovery controls. An evaluation of the relationship between the terminology as applied in NASA model results and the Federal Aviation Regulations will be made as additional full-scale and model test data are obtained.

Effect of Tail Configuration

The results of the tests to determine the spin and recovery characteristics of the model for the normal and criterion spin control conditions (see appendix B) with recovery by rudder reversal only and with recovery by simultaneous reversal of rudder and elevator are of particular importance, since they are used for correlation with the existing tail design criterion. The following discussion covers these tests, but it also covers tests wherein recoveries were attempted by other techniques which might provide additional understanding of the mechanics of spin recovery for light airplanes.

The results indicate that fast, flat spins could be obtained with tails 1, 3, and 4, but not with the remaining six tails. Since there are other similarities of results within these two groupings of tail configurations, the following discussion is presented according to these two groupings of tail configurations.

Tails 1, 3, and 4.- The results shown in figure 11 indicate that a fast, flat spin mode and a steeper spin mode were possible for tails 1, 3, and 4. The steeper spin mode was moderately flat for tails 1 and 3 and moderately steep for tail 4; a moderate rate of rotation accompanied the steeper spin mode. No recovery was obtained from the flat spin mode by any combination of controls.

For the steeper spin modes, satisfactory recoveries by rudder reversal alone were obtained for both the normal and criterion spin for tail 4. For tails 1 and 3, satisfactory recoveries by rudder reversal were obtained from the normal spin control condition, but unsatisfactory recoveries were obtained from the criterion spin control condition. Movement of the elevator down simultaneously with rudder reversal improved the recovery characteristics for tail 1 such that recoveries from the criterion spin were considered satisfactory but did not improve the recovery characteristics for tail 3.

Simultaneous deflection of both the rudder and elevator to neutral for recovery from the criterion spin control condition for the steep spin mode resulted in recoveries that were slow and considered unsatisfactory for the three tail configurations. Moving only the elevator down for tail 3 resulted in no recovery. Changing the aileron deflection from neutral to full against the spin generally increased the angle of attack and retarded the recoveries.

The addition of ventral fin 1 to tail 1 did not eliminate the flat spin mode; however, ventral fin 2, a larger size fin, did eliminate the flat spin mode. (See chart 1(b).) The addition of ventral fin 1 to tail 4 eliminated the flat spin mode, further steepened the spin attitude for the steep spin mode, and improved the recoveries. A ventral fin was not tested on tail 3 for the flat spin mode; however, for the steeper spin mode, no improvements were noted in the recovery characteristics when a ventral fin was added.

<u>Tails 2, 5, 6, 7, 8, and 9</u>.- Only moderately flat and moderately steep spin modes with moderate rates of rotation were obtained for tails 2, 5, 6, 7, 8, and 9. (See fig. 11.) Satisfactory recoveries were obtained from the normal spin control condition by rudder reversal for all tail configurations. For the criterion spin control condition, satisfactory recoveries by rudder reversal were obtained for tails 5, 6, 8, and 9; however, unsatisfactory recoveries were obtained for tails 2 and 7. Also, for all tail configurations, simultaneous reversal of the rudder and movement of the elevator to neutral or down did not improve the recoveries from those obtained by rudder reversal alone.

Simultaneous neutralization of the rudder and elevator resulted in unsatisfactory recoveries for all tail configurations except tail 5. Tail 5 was the only tail configuration of all the tails tested in the present investigation that produced satisfactory spin recoveries by neutralization of the controls. Reversing the elevator alone from up to down resulted in an increased spin rotation and no recovery. Also, deflecting the ailerons against the spin generally resulted in an increase in angle of attack and tended to retard recoveries.

The addition of ventral fins to tails 5, 6, 8, and 9 caused no significant changes in the spin mode or recoveries. However, adding ventral fins to tails 2 and 7 made the spin mode somewhat steeper and reduced the turns for recovery.

Effect of Center-of-Gravity Position

<u>Tails 2, 6, 7, 8, and 9</u>.- Significant changes were noted in the spin attitude when the center of gravity was changed from $0.255\bar{c}$ to $0.145\bar{c}$ for tails 2, 6, 7, 8, and 9. In general, when the center of gravity was moved forward, the angle of attack was reduced by at least 8°, and as much as 20°, and the rate of rotation increased slightly because of the steeper attitudes. There was no appreciable reduction in the turns for recovery, however, probably because of the higher spin rates. Because of the steeper spin modes, some improvement in the recoveries was obtained when the controls were neutralized.

Tails 1, 3, 4, and 5.- In general, no significant changes in the spin and recovery characteristics were noted when the center of gravity was moved forward for tails 1, 3, 4, and 5. For tail 3 the flat spin mode was not evaluated for the forward center-of-gravity position.

Effect of Modifications to Fuselage and Wing Fillets

Description of modifications.- Past investigations (refs. 25 and 26) have indicated that the cross-sectional shape of the fuselage can have significant effects on the spin and recovery characteristics of airplanes. In particular, these studies showed that aft fuselage cross sections having a round bottom and a flat top can produce large antispin aerodynamic yawing moments during spins; whereas cross sections having a flat bottom with sharp edges and a round top may produce large prospin, or propelling, yawing moments during a spin. Most of the spin-tunnel models used in the previous research on spin characteristics had round-bottom fuselages, whereas the aft fuselage cross section of the model used in the present investigation had a bottom which was rectangular in shape.

In view of the potential importance of fuselage shape on spin characteristics and on the application of the TDPF criterion, the present study included an evaluation of the effects produced by several fuselage and fuselage-wing modifications. The modifications were designed with two additional objectives in mind: (1) to determine modifications which might eliminate flat spins, such as those exhibited by tails 1, 3, and 4; and (2) to determine the effects of the modifications on the steep-spin characteristics exhibited by tails 2 and 7, which had shown poor spin-recovery characteristics.

The fuselage and wing fillet modifications evaluated included modified wing-fuselage fillets, a rounded "bathtub" fuselage bottom, rounded fuselage corners, fins on the bottom of the fuselage, and strakes along the aft fuselage. The model results obtained from fuselage-modification tests, as previously mentioned, are presented in figure 9, and the results obtained from tests of the modified wing-fuselage fillets are shown in figure 12.

Since tails 1, 3, and 4 produced similar flat spin modes, only tail 4 was selected for testing, except for determining the effect of wing fillets (in which case tails 1, 3, and 4 were used). Because the purpose of the tests was to eliminate the flat spin modes, only the developed spin modes were investigated, and spin recoveries were not attempted. Both tails 2 and 7 were evaluated for the steep-spin studies, and recoveries from the spins were attempted.

Effect on flat spins.- During exploratory tests with tail 3, it was determined that a very sensitive airflow phenomenon was produced at the trailing edge of the wing at its juncture with the fuselage. One example of this sensitivity is illustrated in figure 12, which indicates that cross-sectional shape of the wing fillet was a very important factor in determining how the model spun when tail 3 was on the model. When the fillet was removed, or when the trailing edge of the fillet was sharpened, the model had a flat spin mode in addition to the steep mode already present; when the fillet was reinstalled with the trailing edge rounded, the flat spin was eliminated, and the model had only the moderately steep spin. These results indicate that the model with tail 3 is on the borderline of a flat spin, since a small change in the fillet appreciably affected the spin characteristics. However, when tails 1 and 4 were tested with the different fillets, the model spin characteristics did not change, in that both the flat and steep spin modes were still present. From these results and other results of fuselage modifications that will be presented, it appears that small configuration changes at the wing-fuselage juncture of the present model caused large changes in the airflow characteristics, which had an appreciable influence on the spin.

The effects of additional modifications on the flat spin, as previously mentioned, are presented in figure 9. These modifications were tested on the model for tail 4 for the flat spin mode only. The results of the tests conducted with a rounded "bathtub" section on the bottom of the aft fuselage indicated that the modification was extremely effective in preventing the flat spin, and the model spun at a steep angle of attack.

Since these results indicated that rounding the entire bottom of the aft fuselage would prevent a flat spin mode, it was decided to determine whether a more simple approach, such as rounding only the bottom sharp edges of the aft fuselage by adding a semicircular cylinder (1.27-cm (0.50-in.) diameter model scale) to each side of the fuselage, would also be effective. Furthermore, since the tests of wing-fillet modifications indicated that there was a sensitive airflow condition at the wing trailing edge at its juncture with the fuselage, the semicircular cylinders were located with the forward ends at the trailing edge of the wing. This modification did not prevent the flat spin for this particular model. The installation of similar semicircular cylinders on another model design with a flat-bottom fuselage did prevent a flat spin, however (unpublished data). Hence, such a modification might be considered for other airplane configurations.

Another modification designed to change the airflow at the wing-fuselage juncture consisted of two fins attached to the bottom of the aft fuselage. (See fig. 9.) Variations of the lateral and longitudinal positions of the fins were tested. For the lateral position tests, the fins were tested in several lateral positions on the fuselage while the forward ends of the fins were kept even with the trailing edge of the wing. When the sides of the fins were flush with the sides of the fuselage (fig. 9), the flat spin was not prevented. Moving both fins laterally inward to a point coinciding with the maximum diameter of the semicircular cylinders (1.27 cm (0.50 in.)) eliminated the flat spin and caused only a steep spin. Further lateral movement of the fins inward, however, reduced the effectiveness of the fins until they no longer prevented the flat spin.

For tests to determine the effect of the longitudinal position of the fins, the lateral position of the fins remained constant at 0.64 cm (0.25 in.) from the sides of the fuselage while the fins were located at several longitudinal positions. Locating the fins so that the forward ends of the fins coincided with the trailing edge of the wing resulted in elimination of the flat spin mode. Locating the fins in a more forward or rearward position generally resulted in a reduction in the effectiveness of the fins for preventing the flat spin. Therefore, it appeared that the most effective longitudinal position of the fins was when the forward ends of the fins were located at the wing trailing edge or slightly aft.

To determine which fin was contributing most to the prevention of the flat spin, the fins were tested individually on each side of the fuselage bottom. When the fin was located on the windward side of the model (pilot's left in right spin), the fin had no significant effect on the spin and the model continued to spin in the flat mode. However, when the fin was located on the leeward side of the model (pilot's right in right spin), the flat spin was eliminated and only the steep spin was obtained.

Strakes were also investigated as another means of attempting to prevent the flat spin. Two lengths of strakes were tested at two different vertical positions (fig. 9). Short strakes in the low position did not prevent the flat spin mode. When the short strakes were raised until they were at the point where the semicircular top of the fuselage became tangent to the flat sides, their effectiveness improved slightly in that the angle of attack decreased slightly, so that the flat spin mode was changed to a moderately flat spin mode. Increasing the length of the strakes did not appear to improve their effectiveness significantly.

To determine whether the strakes were more effective on the windward side or the leeward side of the model in damping the spin rotation, the strakes were tested individually. The strake on the leeward side of the fuselage was ineffective in preventing the flat spin; the strake on the windward side caused the model attitude to steepen and thus indicated that this was the more effective position.

To evaluate the effectiveness of using several of the aforementioned methods for preventing the flat spin, the short strakes and the short semicircular cylinders previously mentioned were tested in combination. (See fig. 9.) The results indicated that this combined modification was more effective than either of these individual modifications, and a very steep spin was obtained.

<u>Effect on steep spins</u>.- In order to determine whether the modifications to the model which were used to prevent the flat spin mode would be effective in improving the spin and recovery characteristics for the steeper spin modes, brief tests were conducted on the model equipped with tails 2 and 7. As previously discussed, with these tail configurations the basic model exhibited a moderately steep spin mode and poor recoveries. When the rounded fuselage bottom or fins on the fuselage bottom were tested individually on the model with either tail, the spin became very steep and recoveries were very rapid.

During the foregoing studies, airflow visualization techniques were used in an attempt to define the flow phenomena associated with the marked effects produced on spin characteristics by the fuselage modifications. However, these tests were uninformative, and it appears that static force tests or rotary-spin force tests will be required to document the phenomena and the attendant effects of Reynolds number on such phenomena.

CORRELATION OF RESULTS WITH TAIL DESIGN CRITERION

Effect of Tail Configurations

One of the primary objectives of the present investigation was to correlate the effect of tail design on the spin and spin-recovery characteristics with results predicted by the tail design criterion. The results already presented indicate that the present criterion cannot provide a reliable prediction of spin and recovery characteristics for several reasons. One reason is that the criterion is for the aileron-neutral condition, whereas aileron deflection has been shown to have a marked effect on spin and recovery characteristics. Furthermore, the criterion considers only tail design parameters although other geometric features such as fuselage cross section, fillet shape, and ventral fins have been shown to have marked effects on spin and recovery characteristics. Another apparent shortcoming of applying the existing tail design criterion for prediction of spin characteristics is the assumption that angle of attack of the spin can be predicted by calculation of the TDR factor. As shown in figure 13, the results obtained for the present model show that the values of angle of attack associated with the various spin modes exhibited by the model with the nine tail configurations generally were considerably higher than values assumed when computing the TDPF used in the tail design criterion.

The actual correlation of the criterion with the results obtained for spin recovery by only rudder reversal for the nine tail configurations is shown in figures 14(a) and 14(b). In these figures, the solid symbols are used to denote tail configurations which were found to have unsatisfactory characteristics, and the open symbols denote configurations with satisfactory characteristics. As shown in figure 14(a), the aileron-neutral results fell on the proper sides of the boundary. However, these results could be misleading because a pilot cannot be expected to hold the ailerons exactly neutral, and the data of figure 14(b) for aileron-deflected (one-third of maximum deflection) conditions showed that a small deflection of the ailerons could cause poor recoveries for configurations which were on the satisfactory side of the boundary and which were considered good when ailerons were neutral (tails 2 and 7).

For the horizontal-tail positions tested, simultaneous reversal of the elevator and rudder for the loading tested in the present investigation did not always aid the spin recovery and in some cases retarded the recovery. As shown in figure 15, the tail design criterion failed to predict correctly the spin-recovery characteristics of tails 2, 3, 6, and 7 when recovery was attempted by simultaneous reversal of the rudder and elevator. The criterion predicted that these recoveries would be satisfactory, but the results of the tests showed that they were unsatisfactory when the ailerons were deflected.

The results also showed that reversing only the elevator (keeping the rudder deflected with the spin) for spin recovery resulted in no recovery. (See charts 1(c) and 3(a).) The explanation for this general lack of effectiveness of elevator for recovery is probably the sequence of control movements for this representative airplane loading condition. The primary recovery control for this loading condition $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$ is the rudder. (See ref. 23.) Since the difference between the rolling and pitching moments of inertia is small, the gyroscopic yawing-moment contribution to recovery is small. Therefore, the proper recovery control for an airplane of this loading is deflection of the rudder to full against the spin followed about 1/2 turn later by deflection of the elevator down (stick forward, see ref. 23). Movement of the rudder first allows the rudder to initially retard the yawing rate before the elevator introduces the nose-down moment. Since the deflection of the rudder and elevator is simultaneous on the spin-tunnel model, the spin-tunnel tests might result in a pessimistic prediction of recoveries attempted by deflection of both the rudder and the elevator. The results of radio-controlled model tests (unpublished) illustrate that recoveries for this particular configuration with the same loading condition are improved by waiting about 1/2 turn after the rudder has been deflected to reverse the elevator.

Thus, the spin-tunnel results obtained with various tail configurations and control manipulations show that a criterion for prediction of spin characteristics of an airplane cannot be based solely on tail design. However, the way in which the tail is designed does have a very large effect on spin and recovery characteristics. For this reason, certain tail design features can be examined to evaluate favorable and adverse design features with regard to the spin and spin recovery.

<u>Effect of vertical position of horizontal tail</u>.- The effect of tail height was generally beneficial, as would be inferred from the TDPF criterion; however, some contrary results were obtained. For example, for the criterion spin control setting, when the horizontal tail was moved up on the vertical tail (tail 2 to tail 7) to increase the magnitude of the TDPF from 348×10^{-6} to 518×10^{-6}, the spin characteristics did not improve, although beneficial effects were expected. In particular, the angle of attack of the spin increased from 47° to 53° and the turns for recovery increased from 3 to 4. In addition, when the configuration was changed from tail 3 to tail 6, the recovery characteristics of the steeper spin mode improved only slightly (although the flat spin mode was eliminated). Thus, even though a large increase in tail damping power factor was obtained in the changes from tails 2 and 3 to tails 7 and 6, respectively, the steep spin modes were changed very little and the turns for recovery improved only slightly.

When tails 2 and 3 were moved to even higher positions on the vertical tail (tails 9 and 8, respectively), a large improvement in the spin and recovery characteristics was obtained. When the horizontal tail was moved from the low position of tail 2 to the much higher position of tail 9, the angle of attack decreased from about 47° to 29° for the criterion spin control condition, and the turns for recovery changed from unsatisfactory to satisfactory. Likewise, changing from tail 3 (low position) to tail 8 (high position) eliminated the flat spin mode and reduced the angle of attack of the steep mode from 52° to approximately 37°. The turns for recovery for the steep spin mode were also reduced from about 3 to 3/4. Therefore, it appears that raising the horizontal tail sufficiently high on the vertical tail to put the value of the TDPF well into the satisfactory region of the tail design criterion can result in a significant improvement in recoveries.

<u>Effect of longitudinal position of horizontal tail</u>.- Moving the horizontal tail from a low forward position (tail 1) to a low rearward position (tail 4) on the fuselage had no significant effect on the flat-spin characteristics of the model but did have a favorable effect on the steep-spin characteristics. For

the steep spin mode, moving the horizontal tail rearward resulted in a steeper spin and rapid recoveries, whereas only unsatisfactory recoveries were obtained with the horizontal tail in the forward position. It is believed that because of the very steep attitude of the spin for tail 4, a large portion of the rudder was unshielded enough to provide an effective rudder for recovery.

Effect of rudder span.- When the rudder span changes, both the TDR and the URVC vary. The effect of this change was evaluated by analyzing the results from tails 2 and 3, 6 and 7, and 8 and 9. The tails in each group are the same except that one tail has a full-span rudder, which results in a relatively large value of URVC, and the other tail has a partial-span rudder, which results in a relatively large value of TDR. Tail 3 (full-span rudder) has both a flat and a steep spin mode. Exchanging URVC for TDR (by changing the full-span rudder to a partial-span one (tail 2)) eliminated the flat spin mode. This result occurred because the damping (TDR) of the tail was increased and at the same time the prospin yawing moment due to the rudder was decreased. The trade-off in this case (decreasing URVC and increasing TDR) was effective in eliminating a flat spin mode but did not improve the recoveries in the steep mode.

For tail 6, which had a full-span rudder, the spin angle of attack was moderate and the recoveries, although marginal, were satisfactory. When the tail damping was increased by using the partial-span rudder (tail 7), the spin angle of attack remained about the same rather than decreasing, and the turns for recovery increased and became unsatisfactory. The recoveries were poor because the angle of attack was not reduced sufficiently to expose the additional rudder area needed for satisfactory recovery. When the rudder deflection was increased on tail 7 to improve the recoveries, the turns for recovery were reduced and became satisfactory. Thus, for tail 7, increasing TDR at the expense of reducing URVC was unfavorable, since the angle of attack was basically unchanged; and because the rudder area needed for recovery was decreased, the recovery characteristics were severely degraded.

Another factor which must be considered in the analysis but is not included in the computation of TDPF is the case in which URVC is increased by extending the rudder to the bottom of the fuselage (and thus decreasing TDR). The increased URVC is assumed to be beneficial for recovery by rudder reversal, but what is not considered is the possible adverse effect of the additional rudder area, which produces an additional prospin yawing moment to the spin before recovery takes place (rudder-with-spin condition). However, in most cases the adverse effect of the prospin input is usually small compared with the beneficial effect of the antispin input provided by the rudder.

For tail 8 (full-span rudder) and tail 9 (partial-span rudder), the spin results were similar in that steep spins and rapid recoveries were obtained. Thus, for these tails, where relatively high values of TDR and URVC were involved, the exchange of TDR for URVC did not appreciably affect the spins or recoveries.

In some cases, usually where good recoveries were obtained, the spin recoveries were not significantly affected by the exchange of URVC for TDR, and in other cases, usually where marginal recoveries were involved, the recoveries were adversely affected. Thus increases in both TDR and URVC are generally necessary in order to improve significantly the spin-recovery characteristics. If the recoveries are borderline, that is, barely satisfactory, the most desirable approach is to increase both URVC and TDR. The geometry of the tail would determine how such an improvement could be accomplished. The addition of a ventral fin is one way to increase TDR. If more drastic measures are required, then the entire tail configuration might have to be revised.

Effect of Ventral Fins

The purpose of adding a ventral fin is to increase the spin damping, which in turn decreases the angle of attack and improves recovery characteristics. However, the results of this investigation indicate that ventral fins do not always produce this desirable effect.

Selected results of the tests to determine the effects of ventral fins are correlated with the existing tail design criterion in figure 16. Inasmuch as the tests were conducted for only the criterion spin condition, the data points reflect conditions involving small aileron deflections. Of particular interest are the data points which denote the results obtained for tail 1 with a ventral fin. It can be seen that when ventral fin 1 was added to tail 1 to increase TDPF from 45×10^{-6} to 405×10^{-6}, the flat spin was not eliminated and the recoveries remained unsatisfactory. This unsatisfactory condition was not predicted by the tail design criterion. For tail 4, which also had a flat spin mode, the addition of ventral fins generally was very effective in preventing the flat spin and resulted in a much steeper spin, from which satisfactory recoveries could be obtained. It should be noticed that when the ventral fin was added to tail 1, the resulting value of TDPF was about the same magnitude as that for tail 2 (see fig. 14(b)), which also did not correlate with the criterion.

It is interesting to note that the addition of ventral fins generally was more effective in reducing the angle of attack for tail designs with partial-span rudders rather than with full-span rudders. Tail 9 was an exception, possibly because the spin mode was so steep even without a ventral fin that the addition of a fin would not be expected to change its attitude appreciably. For the full-span rudder configurations investigated, the ventral fins had little effect on the angle of attack of the spin.

A possible reason why the ventral fins were not as effective in reducing the angle of attack for the full-span rudder configurations as for the partial-span designs is the greater prospin yawing moment provided by the additional rudder area of the full-span configuration. For a full-span rudder configuration, therefore, the ventral fin has an additional yawing moment to oppose and thus appears to be less effective.

It might be assumed that another reason why the ventral fin on a full-span rudder configuration is less effective is the change in yawing moment caused by the forward location of the ventral fin. This change is not considered to be a major contribution, however, since test results with different size ventral fins (which also changed the yawing moment) did not influence the results appreciably.

An indication as to the relative merits of increasing TDPF by two different methods is afforded by the following analysis for tail 3. First, a ventral fin (ventral fin 1) was added to tail 3 to increase the TDPF to 432×10^{-6}, and second, the horizontal tail was moved to the tail 6 position, which increased the TDPF to 500×10^{-6}. Thus, on the basis of these TDPF values, both tails were well into the satisfactory region on the tail design criterion chart for the aileron-deflected condition; however, the results obtained from these two changes were different. The addition of the ventral fin to tail 3 had no favorable effect on the steep spins or recoveries, whereas raising the horizontal tail (tail 6) did have a favorable effect. The foregoing results indicate that the method used to increase the magnitude of the tail damping power factor can have a significant effect on the spin characteristics.

Effect of Center-of-Gravity Position

Although the effects of changes in the center-of-gravity position are not accounted for in the tail design criterion, experience and the previously discussed results in this report indicate that sometimes a relatively small change in center-of-gravity position can result in important changes in the spin and spin-recovery characteristics. The fact that such effects are not accounted for in the tail design criterion is another reason why the criterion may not correctly predict spin characteristics of airplanes.

SUMMARY OF RESULTS

The results of a spin-tunnel investigation with emphasis on the effects of tail configuration on the spinning characteristics of a model of a low-wing, single-engine, light general aviation research airplane are summarized as follows:

(1) Tail configuration can appreciably influence the spin and recovery characteristics. Depending on tail design, the spin and recovery characteristics can change from a flat spin mode with no recovery to a steep spin mode with good recovery.

(2) The results also indicate that many geometric features other than tail configuration affect the spin and recovery characteristics. Some of these features are fuselage cross-sectional shape, ventral fins, strakes, and wing fillets.

(3) Aileron deflection had a marked adverse effect on spin and recovery characteristics when the ailerons were deflected in an adverse direction. Because of the influence of aileron deflection and fuselage modifications on spin and recovery characteristics, the existing tail design criterion, which is based only on aileron-neutral conditions and tail design parameters, did not predict the spin-recovery characteristics of the model correctly for some tail configurations.

(4) A number of modifications to the fuselage, such as rounding the fuselage bottom and adding suitable ventral fins at the tail or under the fuselage-wing juncture, were found to be effective in eliminating a flat-spin condition.

(5) For steep spins, the rounded fuselage bottom and ventral fins under the fuselage-wing juncture improved the recovery characteristics, but the ventral fin located at the tail had little or no effect.

(6) For the model tested, a very sensitive airflow phenomenon existed at the trailing edge of the wing at its juncture with the fuselage. Wing fillets, corner modifications, and ventral fins located in that area resulted in dramatic changes in the spin modes for some tail configurations.

(7) The simultaneous use of elevator reversal (from up to down) with rudder reversal did not necessarily aid the spin recovery and in some cases retarded recovery.

(8) The use of the elevator alone for spin recovery was unsuitable, since it was incapable of terminating the developed spin.

(9) With regard to the overall effects of tail configurations on the spin-recovery characteristics, the T-tail and the tail configurations that had the horizontal tail mounted halfway up on the vertical tail produced the best spin recoveries.

CONCLUSION

On the basis of the results of the present investigation, the tail design criterion for light airplanes, which uses the tail damping power factor (TDPF) as a parameter, cannot be used to predict spin-recovery characteristics. However, certain principles implicit in the criterion are still valid and should be considered when designing a tail configuration for spin recovery. It is important to provide as much damping to the spin as possible (area under the horizontal tail), and it is especially important to provide as much exposed rudder area at spinning attitudes as possible (unshielded rudder volume coefficient (URVC)) in order to provide a large antispin yawing moment for recovery.

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APPENDIX A

METHOD OF COMPUTING TAIL DAMPING POWER FACTOR

The method of computing the tail damping power factor (TDPF) is given in reference 19, and for the convenience of the reader, the procedure is discussed again in this report. A sketch illustrating the factors which are important in the tail configuration for spin recovery is given in figure 17. This figure illustrates the dead-air region over much of the vertical tail, which is caused by the stalled wake of the horizontal tail and which seriously decreases the effectiveness of the rudder. In order to have good rudder effectiveness, a substantial part of the rudder must be outside the horizontal-tail wake. Another important, but less obvious, consideration is that the fixed area beneath the horizontal tail must be sufficient to damp the spinning motion, since it has been found that this area contributes much of the damping of the spinning rotation. The importance of both the foregoing factors are accounted for in the tail damping power factor.

As discussed in reference 17, the rudder must have a substantial amount of area outside the horizontal-tail wake in order to be effective, and also, the fuselage must have a substantial amount of area under the tail in order to provide damping of the spinning rotation. When converted to coefficient form, the unshielded rudder area multiplied by its moment arm from the center of gravity is referred to as the unshielded rudder volume coefficient (URVC), and the fuselage side area under the horizontal tail multiplied by the square of its moment arm is referred to as the tail damping ratio (TDR). These two coefficients are used to calculate the tail damping power factor. When the concept of tail damping power factor was being formulated, some method had to be devised to define the position and extent of the wake of the horizontal tail. An analysis of the model results at that time showed that if the tail damping ratio was less than 0.019, the spin angle of attack (relative wind) could be assumed to be 45° and a wake boundary could be assumed to be defined by the 30° and 60° lines of figure 18. If the tail damping ratio was greater than 0.019, the spin angle of attack (relative wind) could be assumed to be 30° and the wake boundary could be assumed to be defined by the 15° and 45° lines of figure 18.

A particularly important point brought out by the form of the equation for tail damping power factor is that both the fixed area beneath the horizontal tail and the unshielded rudder area are required to give significant values of this parameter. The reasons for this situation are that the damping provided by the fixed area is required to steepen and slow the equilibrium spin, and rudder power is required to provide the change in moment necessary to effect a recovery.

APPENDIX B

TEST METHODS AND PRECISION

Model Testing Technique

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a model for the normal control configuration for spinning (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, or by rapid full reversal of both rudder and elevator. Recovery techniques were varied because the control manipulation required for recovery is primarily dependent on the mass distribution and geometric characteristics of the model (ref. 23).

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 deflection 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 primarily dependent on the mass distribution and geometric characteristics of the model.

Turns for recovery are measured from the time the controls are moved to the time the spin rotation ceases. Recovery characteristics of a model are generally considered satisfactory if all the recoveries that are attempted from the criterion spin in any of the manners previously described are accomplished within $2\frac{1}{4}$ turns or less. This value has been selected on the basis of full-scale-airplane spin-recovery data 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, >91 m/sec (300 ft/sec) 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, for example, >3. A >3-turn recovery, however, does not necessarily indicate an improvement over a >7-turn recovery. A recovery in 10 or more turns is indicated by ∞.

Precision

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

α', deg	± 1
ϕ, deg	± 1
V, percent	± 5
Ω, percent	± 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 the model is difficult to control 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 position, percent $\bar{c}$	± 1
Moments of inertia, percent	± 5

Controls are set within an accuracy of $\pm 1^{\circ}$.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF CORRESPONDING FULL-SCALE AIRPLANE

Overall length with tail 3, m (ft)	5.83 (19.14)
Wing:	
Span, m (ft)	7.46 (24.46)
Area, m^2 (ft^2)	9.11 (98.11)
Root chord, cm (in.)	121.92 (48.0)
Tip chord, cm (in.)	121.92 (48.0)
Mean aerodynamic chord, cm (in.)	121.92 (48.0)
Leading edge of c, distance rearward of leading edge of root chord, cm (in.)	0
Aspect ratio	6.10
Dihedral, deg	5.0
Incidence:	
Root, deg	3.5
Tip, deg	3.5
Airfoil section	NACA 64_2-415 modified
Horizontal tail:	
Span, m (ft)	5.89 (19.32)
Incidence, deg	-3.0
Airfoil section	NACA 65_1-012
Vertical tail:	
Airfoil section	NACA 65_1-012

TABLE II.- DAMPING CHARACTERISTICS OF TAIL CONFIGURATIONS ALONE

AND WITH VENTRAL FINS

Tail configuration	Ventral fin	TDR	URVC	TDPF
1	None	0.009	0.005	45×10^{-6}
	1	0.024	0.017	408×10^{-6}
	2	0.031	0.017	527×10^{-6}
	3	0.021	0.017	357×10^{-6}
2	None	0.029	0.012	348×10^{-6}
	1	0.044	0.012	528×10^{-6}
	1A	0.044	0.012	528×10^{-6}
	2	0.051	0.012	612×10^{-6}
3	None	0.018	0.016	288×10^{-6}
	1	0.027	0.016	432×10^{-6}
	1B	0.027	0.016	432×10^{-6}
	2	0.032	0.016	512×10^{-6}
	3	0.025	0.016	400×10^{-6}
4	None	0.005	0.018	90×10^{-6}
	1	0.016	0.018	288×10^{-6}
	1B	0.016	0.018	288×10^{-6}
	2	0.020	0.027	540×10^{-6}

TABLE II.- Concluded

Tail configuration	Ventral fin	TDR	URVC	TDPF
5	None	0.037	0.041	1510×10^{-6}
	1	0.043	0.041	1760×10^{-6}
6	None	0.025	0.020	500×10^{-6}
	1	0.035	0.020	700×10^{-6}
	1C	0.035	0.020	700×10^{-6}
	2	0.040	0.020	800×10^{-6}
7	None	0.037	0.014	518×10^{-6}
	1	0.052	0.014	728×10^{-6}
	1A	0.052	0.014	728×10^{-6}
	2	0.060	0.014	840×10^{-6}
8	None	0.034	0.028	952×10^{-6}
	1	0.041	0.028	1150×10^{-6}
9	None	0.042	0.019	798×10^{-6}
	1	0.054	0.019	1030×10^{-6}

TABLE III.- MASS CHARACTERISTICS AND INERTIA PARAMETERS OF LOADINGS TESTED ON THE MODEL

[Values given are full scale; moments of inertia are given about center of gravity]

Loading	Weight, N (lb)	Center-of-gravity position		Relative density, μ, at -		Moments of inertia, kg-m^2 (slug-ft^2)			Mass parameters		
		$x/\bar{c}$	$z/\bar{c}$	Sea level	3000 m (10 000 ft)	I_X	I_Y	I_Z	$(I_X - I_Y)/mb^2$	$(I_Y - I_Z)/mb^2$	$(I_Z - I_X)/mb^2$
1	6672 (1500)	0.255	0.048	8.2	11.0	606 (447)	795 (586)	1268 (935)	-50×10^{-4}	-125×10^{-4}	175×10^{-4}
2	6672 (1500)	0.145	0.048	8.2	11.0	606 (447)	795 (586)	1268 (935)	-50×10^{-4}	-125×10^{-4}	175×10^{-4}

FOOTNOTES FOR SPIN CHARTS 1 TO 9

[a]Two conditions possible.

[b]Recovery attempted by deflecting the rudder to 25° against the spin and the elevator to 15° down.

[c]Recovery attempted by deflecting the rudder to 25° against the spin, elevator to 15° down, and the ailerons to 25° with the spin.

[d]Recovery attempted by deflecting the rudder to 35° against the spin, elevator to 15° down, and the ailerons to 25° with the spin.

[e]Recovery attempted by deflecting the rudder to two-thirds against the spin.

[f]Recovery attempted by deflecting the rudder to two-thirds against the spin and the elevator to two-thirds down.

[g]Recovery attempted by deflecting the rudder to two-thirds against the spin and the elevator to neutral.

[h]Recovery attempted by deflecting the rudder and elevator to neutral.

[i]Recovery attempted before final attitude reached.

[j]Recovery attempted by deflecting the elevator to two-thirds down.

[k]Recovery attempted by deflecting the rudder to 25° against the spin.

[l]Recovery attempted by deflecting the rudder to neutral.

[m]Three conditions possible.

[n]Smooth spin with small alternating changes in spin attitude.

[o]Spin alternately changes from a steep to a moderately steep spin mode.

[p]Recovery from steep mode.

[q]Recovery from moderately steep mode.

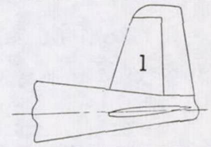
[r]Recovery attempted by deflecting the rudder to neutral and the elevator to two-thirds.

CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 1

(a) Spin characteristics for aft center of gravity

[*Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins)*; U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	Flaps	Altitude	Center-of-gravity position
1	0^o	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

Elevator full up, ailerons full against (a):

80	0	51	3U 2D
26 (84)	0.93 (1.07)	40 (120)	0.43 (2.3)
∞		2, $2\frac{1}{4}$, $2\frac{1}{4}$	

Ailerons 1/3 against (a):

79	0	46	3U 4D
26 (84)	0.94 (1.06)	38 (126)	0.46 (2.2)
$^{e}\infty$		$^{e}2\frac{1}{2}$, $^{e}3$, $^{e}3\frac{1}{2}$	
$^{f}\infty$		$^{f}1\frac{1}{2}$, $^{f}2$, $^{f}2\frac{1}{4}$	
$^{g}\infty$		$^{h}\infty$	
$^{h}\infty$			

Elevator 2/3 up

Elevator full up, ailerons neutral (a):

75	0	48	2U
24 (80)	0.84 (1.2)	35 (116)	0.48 (2.1)
∞		$1\frac{1}{2}$, $1\frac{1}{2}$, $1\frac{1}{2}$	
$^{b}\infty$		$^{b}1$, $^{b}1$, $^{b}1$	
$^{c}\infty$		$^{c}1\frac{1}{2}$, $^{c}1\frac{1}{2}$, $^{c}2$	
$^{d}\infty$			

Elevator full up (Stick back)

Ailerons full against (Stick left)

Ailerons full with (Stick right)

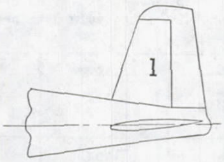
Elevator full down (Stick forward)

α' deg	ϕ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 1.- Continued

(b) Effect of ventral fins

Low-wing model A	R, right
Right erect spins	L, left
Weight, 6672 N (1500 lb)	W, with
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$	A, against
Center of gravity at $0.255\bar{c}$	U, inner wing up
Altitude, 3000 m (10 000 ft)	D, inner wing down



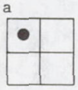
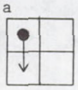
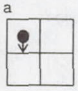
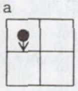
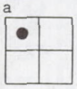
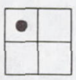
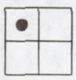
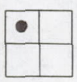
Spin block	α', deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
No ventral fin								
a 	79	0	26 (84)	0.94 (1.06)	25W	16.7U	8.3A	∞
	46	3U 4D	38 (126)	0.46 (2.2)	16.7A	-	-	$2\frac{1}{2}$, 3, $3\frac{1}{2}$
a 	79	0	26 (84)	0.94 (1.06)	25W	16.7U	8.3A	∞
	46	3U 4D	38 (126)	0.46 (2.2)	16.7A	10D	-	$\frac{1}{2}$, 2, $2\frac{1}{4}$
a 	79	0	26 (84)	0.94 (1.06)	25W	16.7U	8.3A	∞
	46	3U 4D	38 (126)	0.46 (2.2)	16.7A	0	-	-
a 	79	0	26 (84)	0.94 (1.06)	25W	16.7U	8.3A	∞
	46	3U 4D	38 (126)	0.46 (2.2)	0	0	-	∞
Ventral fin 1								
a 	75	0	26 (84)	0.79 (1.3)	25W	16.7U	8.3A	∞
	48	1D	35 (116)	0.45 (2.2)	16.7A	-	-	$1\frac{3}{4}$, $2\frac{1}{2}$, $2\frac{1}{2}$
	27	0 4D	58 (190)	0.40 (2.5)	25W	16.7U	8.3A	1
					16.7A	-	-	
	38	0	44 (145)	0.40 (2.5)	25W	16.7U	8.3A	$\frac{3}{4}$, 1, 1
					16.7A	-	-	
	44	2U 6D	38 (126)	0.46 (2.2)	25W	16.7U	8.3A	2, 2, $2\frac{1}{2}$, $2\frac{1}{2}$, 3, $3\frac{1}{2}$
					16.7A	-	-	
	44	2U 6D	38 (126)	0.46 (2.2)	25W	16.7U	8.3A	1, $1\frac{3}{4}$, $1\frac{3}{4}$
					16.7A	10D	-	
	44	2U 6D	38 (126)	0.46 (2.2)	25W	16.7U	8.3A	$1\frac{1}{2}$, $1\frac{1}{2}$, $1\frac{1}{2}$, 2, $2\frac{3}{4}$
					16.7A	0	-	

CHART 1.- Continued

(b) Concluded

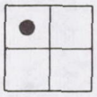
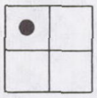
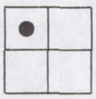
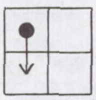
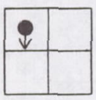
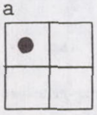
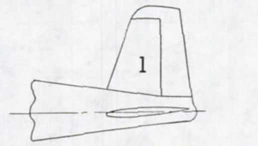
Spin block	Spin characteristics				Control deflection, deg (For spin / For recovery)			Turns for recovery
	α', deg	φ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	δ_r	δ_e	δ_a	
Ventral fin 1								
	44	2U 6D	38 (126)	0.46 (2.2)	25W 0	16.7U 0	8.3A -	3, 3, 4
Ventral fin 2								
	45	3U 2D	40 (130)	0.45 (2.2)	25W 16.7A	16.7U -	8.3A -	1, 1, 1$\frac{1}{2}$
	≈27	≈3D	≈66 (≈217)	0.41 (2.4)	25W 16.7A	16.7U -	8.3A -	$\frac{1}{2}$, 1
			>55 (>180)		25W 16.7A	16.7U -	8.3A -	i$\frac{3}{4}$
			>55 (>180)		25W 16.7A	16.7U 10D	8.3A -	i$\frac{3}{4}$
	45	3U 2D	40 (130)	0.45 (2.2)	25W 16.7A	16.7U 0	8.3A -	1, 1$\frac{3}{4}$
	45	3U 2D	40 (130)	0.45 (2.2)	25W 0	16.7U 0	8.3A -	2$\frac{1}{2}$, 3
Ventral fin 3								
a 	75	1U	26 (84)	0.72 (1.4)	25W 16.7A	16.7U -	8.3A -	∞
	43	1U	40 (130)	0.47 (2.1)				1$\frac{3}{4}$, 2

CHART 1.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
1	0°	3000 m (10 000 ft)	$0.145\bar{c}$



Model values converted to full scale

Elevator full up (Stick back)

a

75	0	45	1D
30 (100)	0.81 (1.2)	41 (136)	0.52 (1.9)
∞		$2\frac{1}{2}$, $2\frac{1}{2}$, $2\frac{3}{4}$	

Ailerons 1/3 against

Elevator 2/3 up

a

75	0	55	2U 3D
28 (93)	0.88 (1.1)	37 (123)	0.57 (1.8)
$^e\infty$		$^e5\frac{1}{4}$, $^e5\frac{1}{2}$, $^e6$	
$^f\infty$		$^f2\frac{1}{2}$, $^f2\frac{1}{2}$, $^f3\frac{1}{2}$	
$^g\infty$		$^g5$	
$^j\infty$		$^j\infty$	

Ailerons full against (Stick left)

Ailerons full with (Stick right)

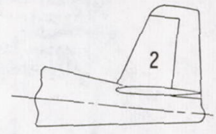
Elevator full down (Stick forward)

α' deg	φ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 2

(a) Spin characteristics for aft center of gravity

[Recovery attempted by *full rudder reversal unless otherwise noted* (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading	
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$	
Tail	Flaps	Altitude	Center-of-gravity position	
2	0°	3000 m (10 000 ft)	$0.255\bar{c}$	

Model values converted to full scale

Ailerons full against, elevator full up (Stick left, stick back):

50	5U 3D
39 (128)	0.41 (2.4)
$2\frac{1}{2}$, $3\frac{1}{2}$, $4\frac{1}{4}$	

Ailerons 1/3 against, Elevator 2/3 up:

47	2D
40 (130)	0.46 (2.2)
$^{e}2$, $^{e}2\frac{1}{4}$, $^{e}3$	
$^{f}2$, $^{f}2\frac{1}{2}$, $^{f}3$	
$^{g}2$, $^{g}2\frac{1}{4}$, $^{g}2\frac{1}{2}$	
$^{h}\infty$	

Elevator full up (Stick back), ailerons neutral:

45	0 6D
40 (130)	0.46 (2.5)
1, 1, 2	

Ailerons full against (Stick left)

Ailerons full with (Stick right)

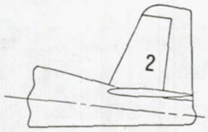
Elevator full down (Stick forward)

α' deg	φ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 2.- Continued

(b) Effect of ventral fins

Low-wing model A	R, right
Right erect spins	L, left
Weight, 6672 N (1500 lb)	W, with
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$	A, against
Center of gravity at $0.255\bar{c}$	U, inner wing up
Altitude, 3000 m (10 000 ft)	D, inner wing down



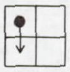
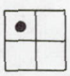
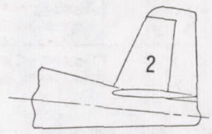
Spin block	Spin characteristics: α', deg	Spin characteristics: φ, deg	Spin characteristics: V, m/sec (ft/sec)	Spin characteristics: Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
No ventral fin								
	47	2D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / -	8.3A / -	2, $2\frac{1}{4}$, 3
	47	2D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / 10D	8.3A / -	2, $2\frac{1}{2}$, 3
	47	2D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / 0	8.3A / -	2, $2\frac{1}{4}$, $2\frac{1}{2}$
	47	2D	40 (130)	0.46 (2.2)	25W / 0	16.7U / 0	8.3A / -	∞
Ventral fin 1								
	-	-	>55 (>180)	-	25W / 16.7A	16.7U / -	8.3A / -	[i]$\frac{1}{2}$
	-	-	>55 (>180)	-	25W / 16.7A	16.7U / 10D	8.3A / -	[i]$\frac{1}{2}$, [i]$\frac{1}{2}$
	-	-	>55 (>180)	-	25W / 16.7A	16.7U / 0	8.3A / -	[i]$\frac{1}{4}$, [i]$\frac{1}{4}$
	-	-	>55 (>180)	-	25W / 0	16.7U / 0	8.3A / -	[i]$\frac{1}{4}$
Ventral fin 1A								
	-	-	>55 (>180)	-	25W / 16.7A	16.7U / -	8.3A / -	[i]$\frac{1}{2}$
	-	-	>55 (>180)	-	25W / 0	16.7U / 0	8.3A / -	[i]$\frac{1}{2}$
Ventral fin 2								
	-	-	>55 (>180)	-	25W / 16.7A	16.7U / -	8.3A / -	[i]$\frac{1}{2}$, [i]$\frac{1}{2}$

CHART 2.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed *spin data presented for rudder-full-with spins*); *U*, inner wing up; *D*, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	Flaps	Altitude	Center-of-gravity position
2	0°	3000 m (10 000 ft)	$0.145\bar{c}$



Model values converted to full scale

Elevator full up (Stick back)

a

42	3U 6D	27	2U 4D
45 (146)	0.50 (2.0)	54 (176)	0.52 (1.9)
$1\frac{1}{2}$, 2			

Ailerons 1/3 against

Elevator 2/3 up

a

48	2U 2D		
39 (129)	0.52 (1.9)	≈64 (≈209)	0.59 (1.7)
${}^{e}4$, ${}^{e}4$			
${}^{f}3\frac{1}{2}$, ${}^{f}4$			
${}^{g}2$, ${}^{g}2\frac{3}{4}$, ${}^{g}3$			
${}^{h}5\frac{1}{2}$			

Ailerons full against (Stick left)

Ailerons full with (Stick right)

Elevator full down (Stick forward)

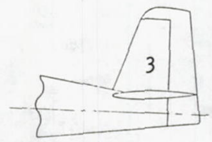
α' deg	φ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 3

(a) Spin characteristics for aft center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
3	0^o	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

Ailerons 1/3 against (elevator neutral), a:

83	2U 3D	55	0
26 (84)	0.84 (1.2)	35 (114)	0.50 (2.0)
∞		2, $2\frac{1}{4}$, $2\frac{1}{2}$	

Ailerons 1/3 against, a; Elevator 2/3 up:

81	2U 2D	52	3D
30 (98)	0.79 (1.3)	35 (116)	0.50 (2.0)
$^{e}\infty$		$^{e}2$, $^{e}2\frac{1}{4}$, $^{e}3$	
		$^{k}2$, $^{k}2$, $^{k}2\frac{1}{2}$	
		$^{f}1\frac{3}{4}$, $^{f}2\frac{1}{2}$, $^{f}3\frac{1}{2}$	
		$^{g}3$, $^{g}3\frac{1}{2}$, $^{g}4$	
		$^{l}>3$, $^{l}3\frac{1}{2}$	
		$^{h}\infty$	
		$^{j}\infty$	

Elevator full up (Stick back), a:

80	2U 2D	52	2D
26 (84)	0.75 (1.3)	35 (116)	0.50 (2.0)
$5\frac{1}{2}$, $7\frac{1}{2}$		1, 1, $1\frac{1}{4}$	
		$^{b}1\frac{1}{2}$, $^{b}2$, $^{b}2$	

45	6D
40 (130)	0.46 (2.2)
$\frac{3}{4}$, 1	

Ailerons full against (Stick left), a:

78	4U 2D	56	2U
30 (100)	0.75 (1.3)	34 (112)	0.54 (1.9)
$8\frac{1}{2}$		2, $2\frac{1}{2}$, $2\frac{1}{2}$	

Neutral controls, a:

82	0 3D	51	4U 4D
26 (84)	0.84 (1.2)	35 (116)	0.53 (1.9)
∞		2, 2, $2\frac{1}{2}$	

Ailerons full with (Stick right):

>55 (>180)	
$^{i}1$, $^{i}1$	

Elevator full down (Stick forward):

56	2U
33 (107)	0.59 (1.7)
$2\frac{1}{4}$, $2\frac{1}{2}$, $2\frac{1}{2}$	

50	2U 3D
35 (114)	0.55 (1.2)
2, $2\frac{1}{2}$, $3\frac{1}{4}$	

>55 (>180)	
$^{i}1$, $^{i}1$	

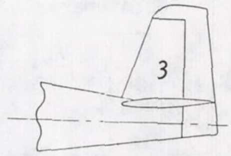
α' deg	φ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 3.- Continued

(b) Effect of ventral fins

Low-wing model A
Right erect spins
Weight, 6672 N (1500 lb)
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Center of gravity at $0.255\bar{c}$
Altitude, 3000 m (10 000 ft)

R, right
L, left
W, with
A, against
U, inner wing up
D, inner wing down



Spin block	α', deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	δ_r (For spin / For recovery)	δ_e (For spin / For recovery)	δ_a (For spin / For recovery)	Turns for recovery
No ventral fin								
a	81	2U 2D	30 (98)	0.79 (1.3)	25W	16.7U	8.3A	∞
	52	3D	35 (116)	0.50 (2.0)	16.7A	-	-	2, $2\frac{1}{4}$, 3
a	81	2U 2D	30 (98)	0.79 (1.3)	25W	16.7U	8.3A	-
	52	3D	35 (116)	0.50 (2.0)	16.7A	10D	0	$1\frac{3}{4}$, $2\frac{1}{2}$, $3\frac{1}{2}$
a	81	2U 2D	30 (98)	0.79 (1.3)	25W	16.7U	8.3A	-
	52	3D	35 (116)	0.50 (2.0)	16.7A	0	-	3, $3\frac{1}{2}$, 4
a	81	2U 2D	30 (98)	0.79 (1.3)	25W	16.7U	8.3A	∞
	52	3D	35 (116)	0.50 (2.0)	0	0	-	∞
Ventral fin 1								
	55	3U 2D	35 (116)	0.54 (1.9)	25W / 16.7A	16.7U / -	8.3A / -	$1\frac{1}{2}$, $2\frac{1}{4}$, $2\frac{1}{2}$,
	55	3U 2D	35 (116)	0.54 (1.9)	25W / 16.7A	16.7U / -	8.3A / -	2, $2\frac{1}{2}$, 3
	55	3U 2D	35 (116)	0.54 (1.9)	25W / 16.7A	16.7U / 0	8.3A / -	2, $2\frac{1}{4}$, 3
	55	3U 2D	35 (116)	0.54 (1.9)	25W / 0	16.7U / 0	8.3A / -	4, >5, >5
Ventral fin 1B								
	58	3U 3D	35 (114)	0.54 (1.9)	25W / 16.7A	16.7U / -	8.3A / -	$1\frac{1}{2}$, $2\frac{1}{4}$, $2\frac{1}{4}$

CHART 3.- Continued

(b) Concluded

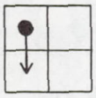
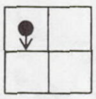
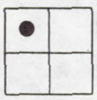
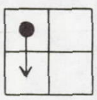
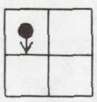
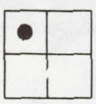
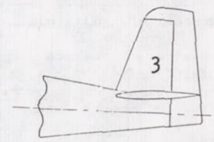
Spin block	α', deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery) δ_r	δ_e	δ_a	Turns for recovery
Ventral fin 1B								
	58	3U 3D	35 (114)	0.54 (1.9)	25W / 16.7A	16.7U / 10D	8.3A / -	$2\frac{1}{2}$, $2\frac{1}{2}$, $2\frac{3}{4}$
	58	3U 3D	35 (114)	0.54 (1.9)	25W / 16.7A	16.7U / 0	8.3A / -	$2\frac{1}{4}$, $2\frac{3}{4}$, $2\frac{3}{4}$
	58	3U 3D	35 (114)	0.54 (1.9)	25W / 0	16.7U / 0	8.3A / -	6, $6\frac{1}{4}$
Ventral fin 2								
	57	2U	36 (119)	0.50 (2.0)	25W / 16.7A	16.7U / -	8.3A / -	$1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{1}{2}$
	57	2U	36 (119)	0.50 (2.0)	25W / 16.7A	16.7U / 10D	8.3A / -	$1\frac{1}{2}$, $1\frac{1}{2}$, $1\frac{3}{4}$
	57	2U	36 (119)	0.50 (2.0)	25W / 16.7A	16.7U / 0	8.3A / -	$1\frac{3}{4}$, $1\frac{3}{4}$, $1\frac{3}{4}$
	57	2U	36 (119)	0.50 (2.0)	25W / 0	16.7U / 0	8.3A / -	$3\frac{3}{4}$, 4, $6\frac{1}{2}$
Ventral fin 3								
	51	2D	37 (121)	0.47 (2.1)	25W / 16.7A	16.7U / -	8.3A / -	$1\frac{3}{4}$, $1\frac{3}{4}$, 2

CHART 3.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading	
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$	
Tail	Flaps	Altitude	Center-of-gravity position	
3	0^o	3000 m (10 000 ft)	$0.145\bar{c}$	

Model values converted to full scale

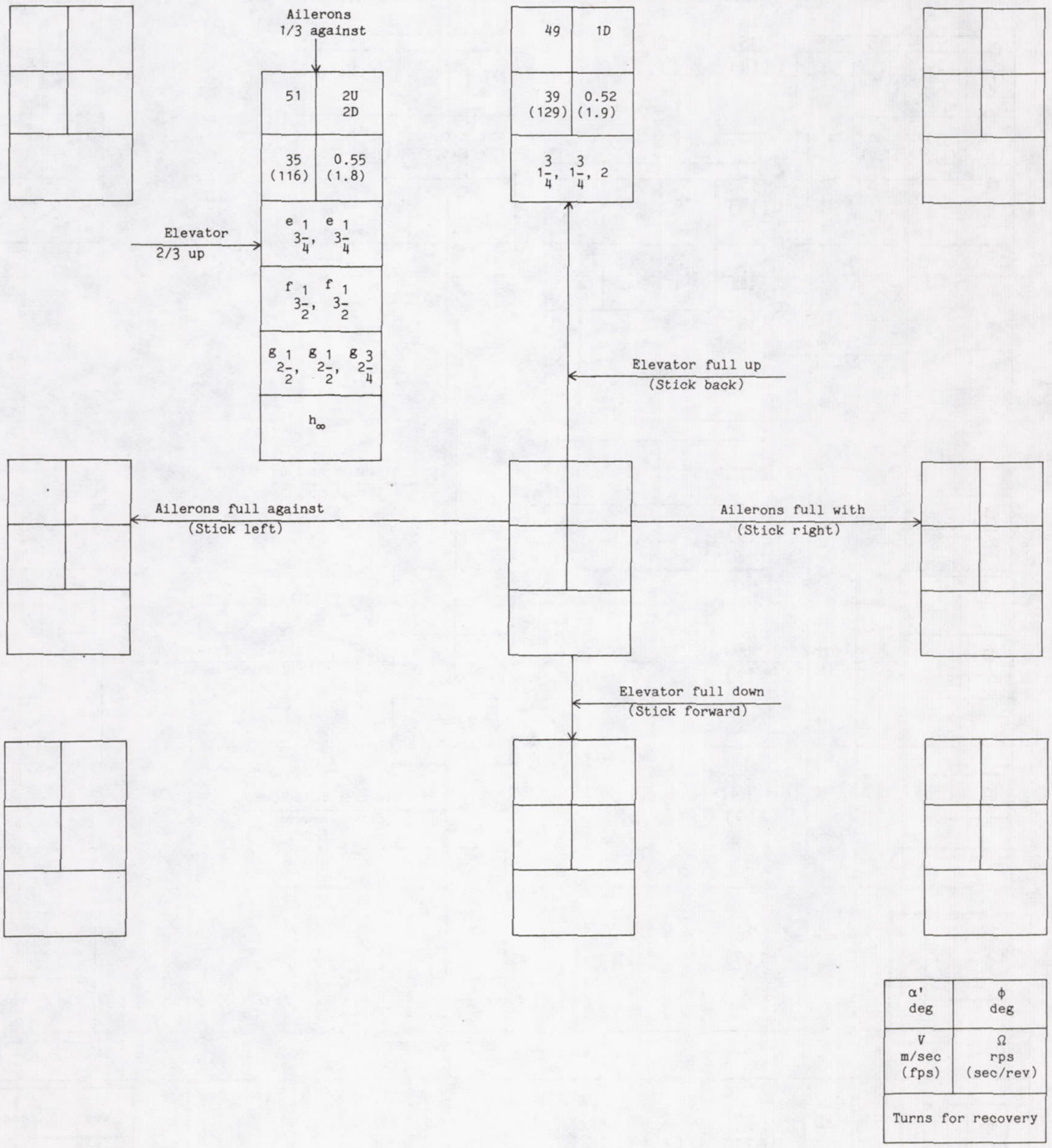
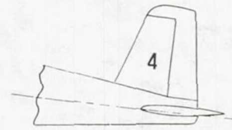


CHART 4.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 4

(a) Spin characteristics for aft center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
4	0°	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

a

78	2U 3D	42	5U 0
25 (82)	0.94 (1.06)	40 (130)	0.41 (2.4)
∞		1, 1, $1\frac{1}{4}$	

Ailerons 1/3 against

a

77	1D	35	5U 0
25 (82)	0.97 (1.0)	44 (145)	0.45 (2.2)
$^{e}\infty$		$^{e}1$, $^{e}1\frac{1}{4}$, $^{e}1\frac{1}{4}$	
$^{f}9\frac{1}{2}$		$^{f}1$, $^{f}1$	
$^{g}\infty$		$^{g}1\frac{1}{4}$, $^{g}1\frac{1}{2}$, $^{g}1\frac{1}{2}$	
$^{h}\infty$		$^{h}1$, $^{h}2$, $^{h}>2\frac{3}{4}$	

Elevator 2/3 up

a

77	1D	38	3D
26 (84)	0.90 (1.1)	42 (138)	0.40 (2.5)
∞		$\frac{1}{2}$, $\frac{1}{2}$, 1	

Elevator full up (Stick back)

Ailerons full against (Stick left)

Ailerons full with (Stick right)

Elevator full down (Stick forward)

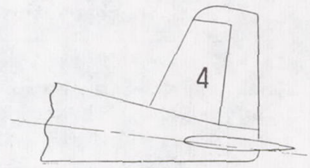
α' deg	ϕ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 4.- Continued

(b) Effect of ventral fins

[Low-wing model A
Right erect spins
Weight, 6672 N (1500 lb)
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Center of gravity at $0.255\bar{c}$
Altitude, 3000 m (10 000 ft)

R, right
L, left
W, with
A, against
U, inner wing up
D, inner wing down]



Spin block	Spin characteristics: α', deg	φ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
No ventral fin								
a	77	1D	25 (82)	0.97 (1.0)	25W / 16.7A	16.7U / -	8.3A / -	∞
	35	5U 0	44 (145)	0.45 (2.2)				1, $1\frac{1}{4}$, $1\frac{1}{4}$
a	77	1D	25 (82)	0.97 (1.0)	25W / 16.7A	16.7U / 10D	8.3A / -	$9\frac{1}{2}$
	35	5U 0	44 (145)	0.45 (2.2)				1, 1
a	77	1D	25 (82)	0.97 (1.0)	25W / 16.7A	16.7U / 0	8.3A / -	∞
	35	5U 0	44 (145)	0.45 (2.2)				$1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{1}{2}$
a	77	1D	25 (82)	0.97 (1.0)	25W / 0	16.7U / 0	8.3A / -	∞
	35	5U 0	44 (145)	0.45 (2.2)				1, 2, $>2\frac{3}{4}$
Ventral fin 1								
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / -	8.3A / -	i$\frac{3}{4}$
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / 10D	8.3A / -	i$\frac{1}{4}$
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / 0	8.3A / -	i$\frac{3}{4}$
	-	-	≈55 (≈180)	-	25W / 0	16.7U / 0	8.3A / -	i$_1$

CHART 4.- Continued

(b) Concluded

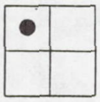
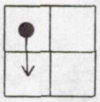
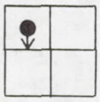
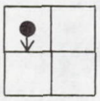
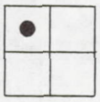
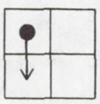
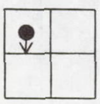
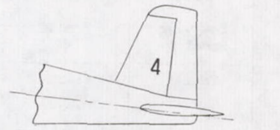
Spin block	Spin characteristics: α', deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
Ventral fin 1B								
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / -	8.3A / -	[i]1
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / 10D	8.3A / -	[i]$\frac{1}{4}$
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / 0	8.3A / -	[i]$\frac{1}{2}$
	-	-	≈55 (≈180)	-	25W / 0	16.7U / 0	8.3A / -	[i]1
Ventral fin 2								
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / -	8.3A / -	[i]1
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / 10D	8.3A / -	[i]$\frac{1}{4}$
	-	-	≈55 (≈180)	-	25W / 16.7A	16.7U / 0	8.3A / -	[i]$\frac{1}{2}$
	-	-	≈55 (≈180)	-	25W / 0	16.7U / 0	8.3A / -	[i]$\frac{3}{4}$

CHART 4.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
4	0°	3000 m (10 000 ft)	$0.145\bar{c}$



Model values converted to full scale

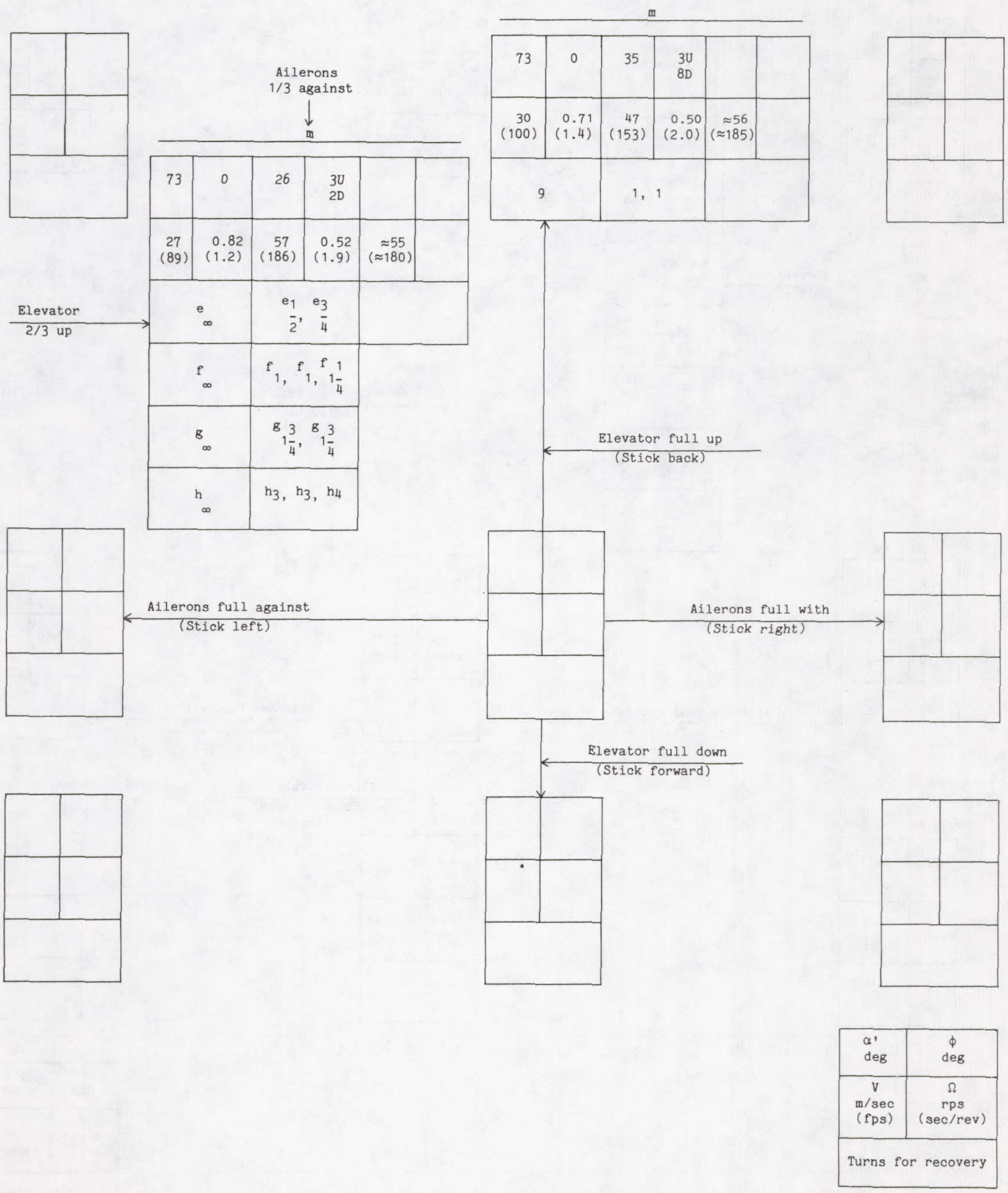
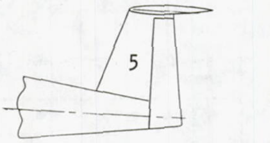


CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 5

(a) Spin characteristics for aft center of gravity

[**Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down**]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
5	0°	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

47	6U 8D
40 (130)	0.41 (2.4)
$\frac{1}{2}, \frac{1}{2}, \frac{1}{2}$	

Ailerons 1/3 against

Elevator 2/3 up

41	5U 4D
44 (145)	0.44 (2.3)
$^{e}\frac{1}{2}, {}^{e}\frac{3}{4}, {}^{e}1$	
$^{f}1, {}^{f}1$	
$^{g}\frac{3}{4}, {}^{g}1$	
$^{h}1\frac{1}{4}, {}^{h}2, {}^{h}2\frac{1}{4}$	
$^{j}\infty$	

47	3U 9D
40 (130)	0.44 (2.3)
$\frac{1}{2}, \frac{3}{4}, 1$	

49	5D
40 (130)	0.46 (2.2)
$\frac{1}{2}, \frac{3}{4}$	

Elevator full up (Stick back)

21	5U
58 (190)	0.72 (1.4)
$\frac{1}{2}$	

Ailerons full against (Stick left)

>55 (>180)	0.84 (1.2)

Ailerons full with (Stick right)

>69 (>225)	

Elevator full down (Stick forward)

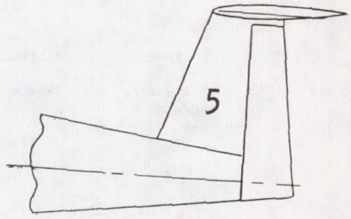
22	10U
58 (190)	0.85 (1.2)

21	0 12U
59 (195)	0.94 (1.1)

α' deg	ϕ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 5.- Continued

(b) Effect of ventral fins



Low-wing model A	R, right
Right erect spins	L, left
Weight, 6672 N (1500 lb)	W, with
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$	A, against
Center of gravity at $0.255\bar{c}$	U, inner wing up
Altitude, 3000 m (10 000 ft)	D, inner wing down

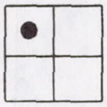
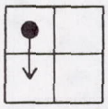
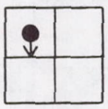
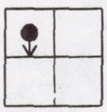
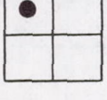
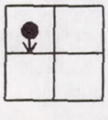
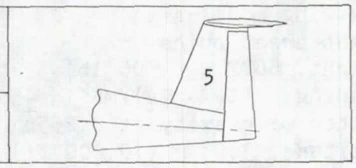
Spin block	Spin characteristics: α', deg	φ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
No ventral fin								
	41	5U 4D	44 (145)	0.44 (2.3)	25W / 16.7A	16.7U / -	8.3A / -	$\frac{1}{2}$, $\frac{3}{4}$, 1
	41	5U 4D	44 (145)	0.44 (2.3)	25W / 16.7A	16.7U / 10D	8.3A / -	1, 1,
	41	5U 4D	44 (145)	0.44 (2.3)	25W / 16.7A	16.7U / 0	8.3A / -	$\frac{3}{4}$, 1
	41	5U 4D	44 (145)	0.44 (2.3)	25W / 0	16.7U / 0	8.3A / -	$1\frac{1}{4}$, 2, $2\frac{1}{4}$
Ventral fin 1								
	47	4U 6D	40 (130)	0.42 (2.4)	25W / 16.7A	16.7U / -	8.3A / -	$\frac{3}{4}$, 1
	47	4U 6D	40 (130)	0.42 (2.4)	25W / 0	16.7U / 0	8.3A / -	2, $2\frac{3}{4}$

CHART 5.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	Flaps	Altitude	Center-of-gravity position
5	0°	3000 m (10 000 ft)	$0.145\bar{c}$



Model values converted to full scale

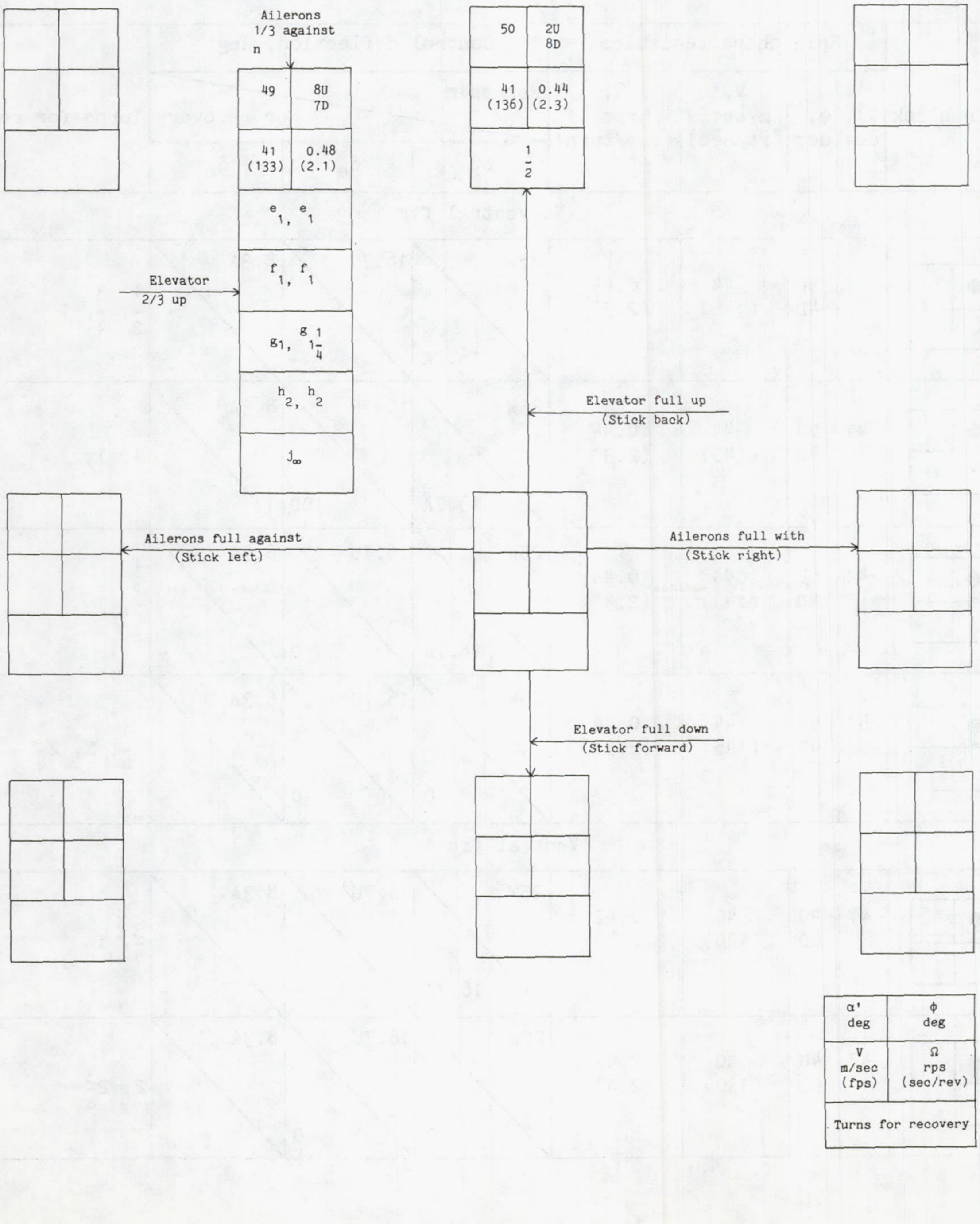
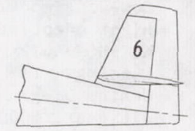


CHART 6.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 6

(a) Spin characteristics for aft center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	Flaps	Altitude	Center-of-gravity position
6	0^o	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

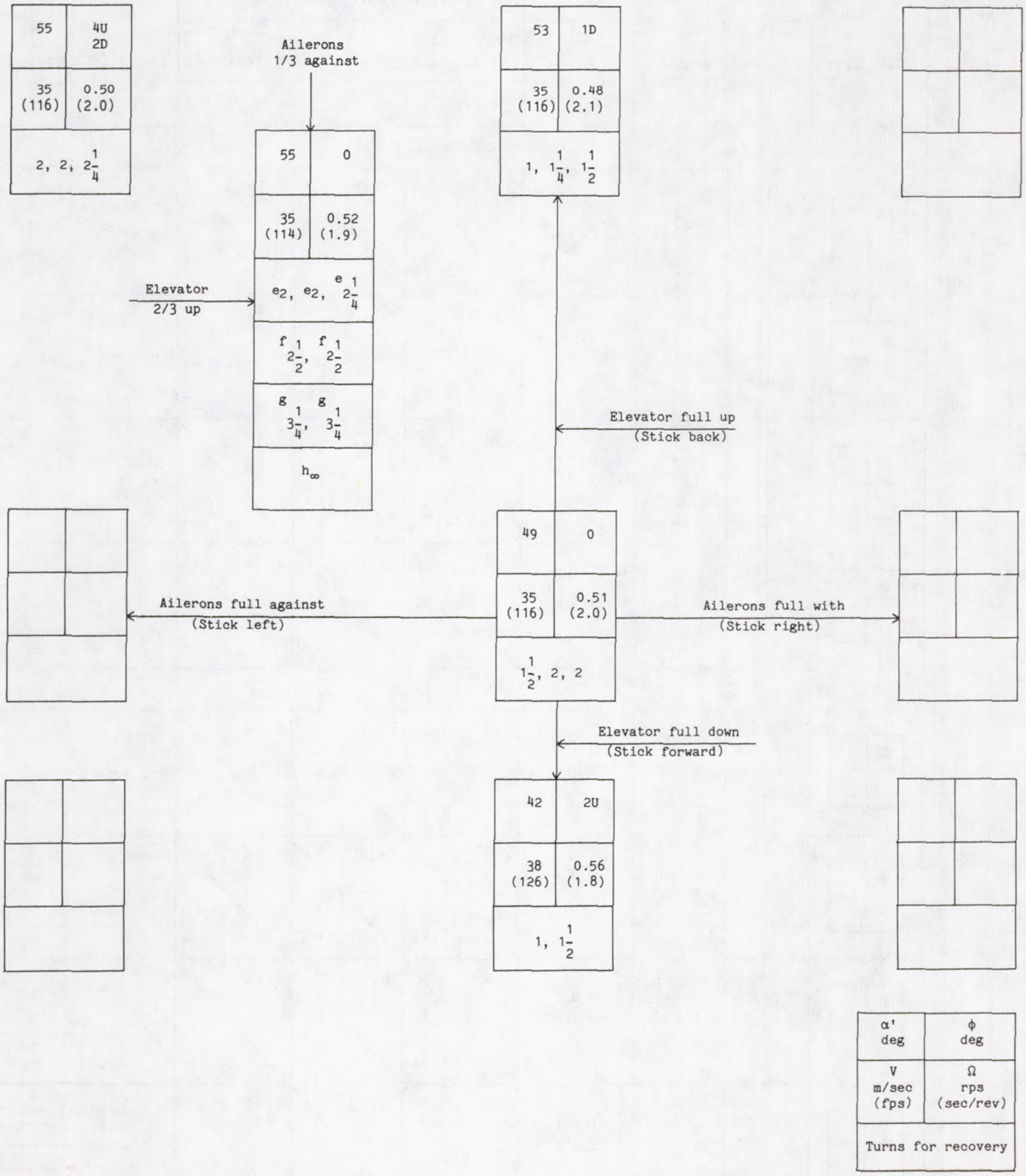
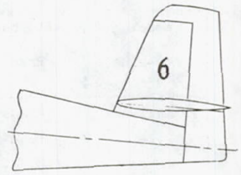


CHART 6.- Continued

(b) Effect of ventral fins

Low-wing model A Right erect spins Weight, 6672 N (1500 lb) Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$ Center of gravity at $0.255\bar{c}$ Altitude, 3000 m (10 000 ft)	R, right L, left W, with A, against U, inner wing up D, inner wing down



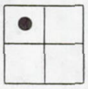
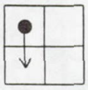
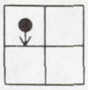
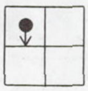
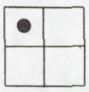
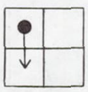
Spin block	Spin characteristics				Control deflection, deg (For spin / For recovery)			Turns for recovery
	α', deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	δ_r	δ_e	δ_a	
No ventral fin								
	55	0	35 (114)	0.52 (1.9)	25W / 16.7A	16.7U / -	8.3A / -	2, 2, $2\frac{1}{4}$
	55	0	35 (114)	0.52 (1.9)	25W / 16.7A	16.7U / 10D	8.3A / -	$2\frac{1}{2}$, $2\frac{1}{2}$
	55	0	35 (114)	0.52 (1.9)	25W / 16.7A	16.7U / 0	8.3A / -	$3\frac{1}{4}$, $3\frac{1}{2}$
	55	0	35 (114)	0.52 (1.9)	25W / 0	16.7U / 0	8.3A / -	4, >6, ∞
Ventral fin 1								
	53	2U 2D	35 (114)	0.49 (2.0)	25W / 16.7A	16.7U / -	8.3A / -	$1\frac{3}{4}$, $2\frac{1}{4}$, $2\frac{1}{2}$
	53	2U 2D	35 (114)	0.49 (2.0)	25W / 16.7A	16.7U / 10D	8.3A / -	$1\frac{3}{4}$, $1\frac{3}{4}$
	53	2U 2D	35 (114)	0.49 (2.0)	25W / 16.7A	16.7U / 0	8.3A / -	$1\frac{1}{2}$, $1\frac{3}{4}$, $2\frac{1}{2}$
	53	2U 2D	35 (114)	0.49 (2.0)	25W / 0	16.7U / 0	8.3A / -	∞

CHART 6.- Continued

(b) Concluded

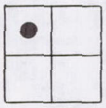
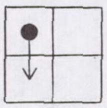
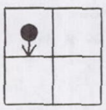
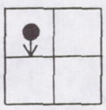
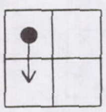
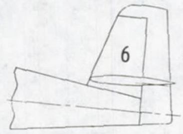
Spin block	Spin characteristics: α', deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
Ventral fin 1C								
	53	3U 2D	35 (114)	0.50 (2.0)	25W / 16.7A	16.7U / -	8.3A / -	$1\frac{3}{4}$, $1\frac{3}{4}$, 1
	53	3U 2D	35 (114)	0.50 (2.0)	25W / 16.7A	16.7U / 10D	8.3A / -	$1\frac{3}{4}$, 2, 2
	53	3U 2D	35 (114)	0.50 (2.0)	25W / 16.7A	16.7U / 0	8.3A / -	2, 2, 2
	53	3U 2D	35 (114)	0.50 (2.0)	25W / 0	16.7U / 0	8.3A / -	∞
Ventral fin 2								
	54	2U 3D	35 (114)	0.48 (2.1)	25W / 0	16.7U / 10D	8.3A / -	$2\frac{1}{2}$, 3, 3

CHART 6.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	Flaps	Altitude	Center-of-gravity position
6	0°	3000 m (10 000 ft)	$0.145\bar{c}$



Model values converted to full scale

Ailerons 1/3 against; Elevator full up (Stick back):

47	2U 2D
39 (129)	0.53 (1.9)
$e\ 2\frac{1}{4}$, $e\ 2\frac{1}{4}$, $e\ 2\frac{1}{4}$	

Elevator 2/3 up:

$e\ 2\frac{1}{4}$, $e\ 2\frac{1}{4}$, $e\ 2\frac{1}{4}$
$f\ 1\frac{1}{2}$, $f\ 2$, $f\ 2\frac{1}{2}$
$g\ 2$, $g\ 2$, $g\ 2\frac{1}{4}$
$h\ 4\frac{1}{2}$

Ailerons neutral; Elevator full up (Stick back):

45	4U 5D
42 (139)	0.50 (2.0)
$1\frac{1}{2}$, $1\frac{1}{2}$, $1\frac{1}{2}$	

Ailerons full against (Stick left)

Ailerons full with (Stick right)

Elevator full down (Stick forward)

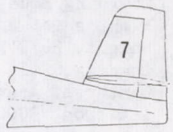
α' deg	φ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 7.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 7

(a) Spin characteristics for aft center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
7	0°	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

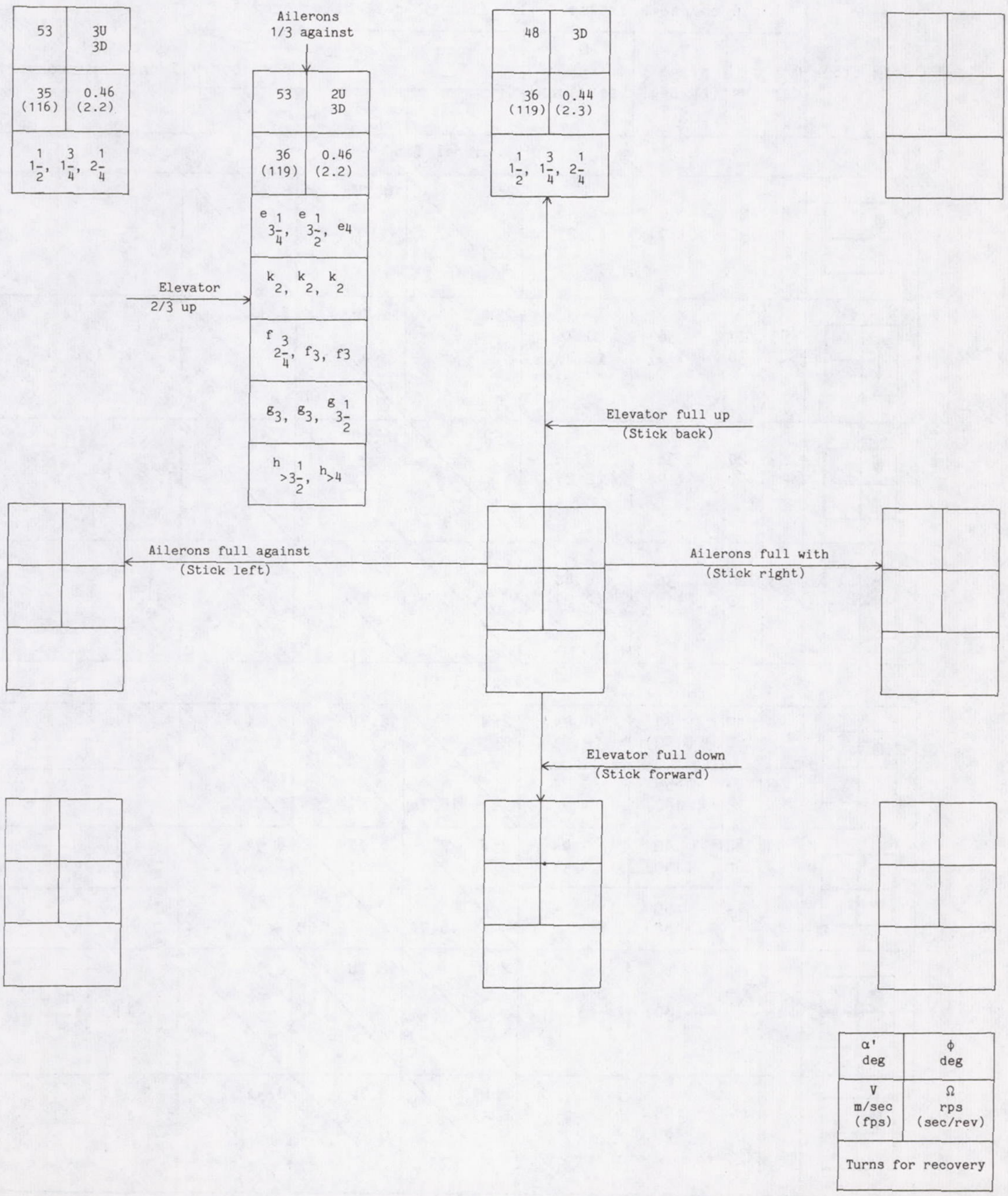
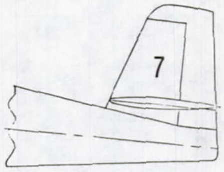


CHART 7.- Continued

(b) Effect of ventral fins



Low-wing model A
Right erect spins
Weight, 6672 N (1500 lb)
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Center of gravity at $0.255\bar{c}$
Altitude, 3000 m (10 000 ft)

R, right
L, left
W, with
A, against
U, inner wing up
D, inner wing down

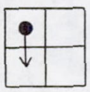
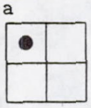
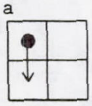
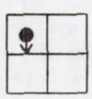
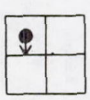
Spin block	Spin characteristics: α', deg	φ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
No ventral fin								
	53	2U 3D	36 (119)	0.46 (2.2)	25W / 16.7A	16.7U / -	8.3A / -	$3\frac{1}{4}$, $3\frac{1}{2}$, 4
	53	2U 3D	36 (119)	0.46 (2.2)	25W / 16.7A	16.7U / 10D	8.3A / -	$2\frac{3}{4}$, 3, 3
	53	2U 3D	36 (119)	0.46 (2.2)	25W / 16.7A	16.7U / 0	8.3A / -	3, 3, $3\frac{1}{2}$
	53	2U 3D	36 (119)	0.46 (2.2)	25W / 0	16.7U / 0	8.3A / -	$>3\frac{1}{2}$, >4
Ventral fin 1								
a 	44	4U 6D	40 (130)	0.44 (2.3)	25W / 16.7A	16.7U / -	8.3A / -	$\frac{1}{2}$, $1\frac{1}{2}$, $1\frac{1}{2}$
	-	-	>55 (>180)	-				-
a 	44 -	4U 6D	40 (130)	0.44 (2.3)	25W / 16.7A	16.7U / 10D	8.3A / -	$1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, 2
	-	-	>55 (>180)	-				i$\frac{1}{2}$
	-	-	>55 (>180)	-	25W / 16.7A	16.7U / 0	8.3A / -	i$\frac{3}{4}$, i1, i$1\frac{1}{4}$
	-	-	>55 (>180)	-	25W / 0	16.7U / 0	8.3A / -	i$\frac{3}{4}$, i$1\frac{3}{4}$

CHART 7.- Continued

(b) Concluded

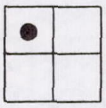
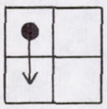
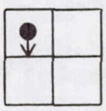
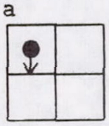
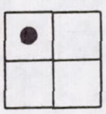
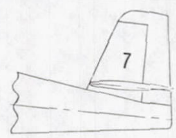
Spin block	α', deg	φ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg: For spin / For recovery, δ_r	δ_e	δ_a	Turns for recovery
Ventral fin 1A								
a 	49	2U 4D	≈40 (≈130)	0.46 (2.2)	25W	16.7U	8.3A	1, $1\frac{3}{4}$, $1\frac{3}{4}$
	-	-	>55 (>180)	-	16.7A	-	-	-
a 	49	2U 4D	≈40 (≈130)	0.46 (2.2)	25W	16.7U	8.3A	$1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{1}{2}$
	-	-	>55 (>180)	-	16.7A	10D	-	-
a 	49	2U 4D	≈40 (≈130)	0.46 (2.2)	25W	16.7U	8.3A	$1\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$
	-	-	>55 (>180)	-	16.7A	0	-	[i]1
a 	49	2U 4D	≈40 (≈130)	0.46 (2.2)	25W	16.7U	8.3A	$1\frac{1}{2}$, $>2\frac{1}{2}$, $2\frac{3}{4}$
	-	-	>55 (>180)	-	0	0	-	[i]1
Ventral fin 2								
	-	-	>55 (>180)	- (2.2)	25W	16.7U	8.3A	[i]$1\frac{1}{2}$, $1\frac{3}{4}$, $2\frac{1}{4}$
					16.7A	-	-	

CHART 7.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading	
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$	
Tail	Flaps	Altitude	Center-of-gravity position	
7	0°	3000 m (10 000 ft)	$0.145\bar{c}$	

Model values converted to full scale

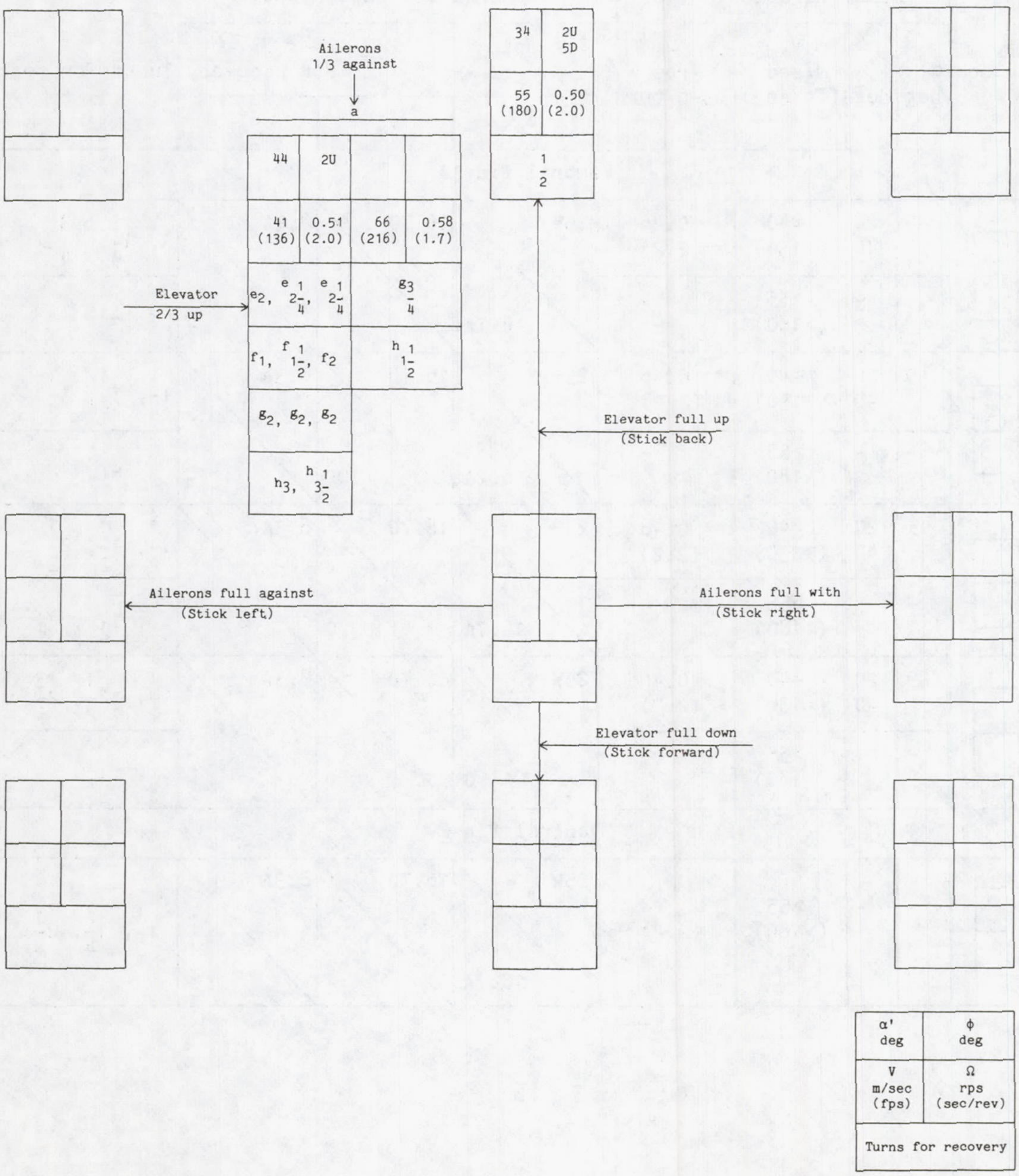
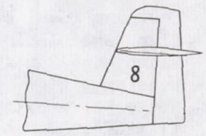


CHART 8.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 8

(a) *Spin characteristics for aft center of gravity*

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
8	0^{o}	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

Elevator full up (Stick back), ailerons full against (top left box):

48	7U 5D
40 (130)	0.41 (2.4)
$\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$	

Ailerons 1/3 against; Elevator 2/3 up:

a

44	2U 7D	37	4D
40 (130)	0.42 (2.4)	48 (159)	0.37 (2.7)
$^{e}\frac{1}{2}$, $^{e}\frac{3}{4}$		$^{e}\frac{3}{4}$	
f_1, $^{f}1\frac{1}{4}$		$^{h}>2\frac{1}{2}$	
g_1, g_1			
$^{h}>3\frac{1}{2}$			

Elevator full up (Stick back):

48	1U 7D
41 (135)	0.45 (2.2)
$\frac{1}{2}$, $\frac{1}{2}$, $\frac{3}{4}$	

Ailerons 1/3 with; Elevator 2/3 up:

45	2U 1D
40 (130)	0.46 (2.2)
$^{e}\frac{3}{4}$, e_1, e_1	
f_1, $^{f}1\frac{1}{4}$, $^{f}1\frac{1}{4}$	
g_1, $^{g}1\frac{1}{4}$, $^{g}1\frac{1}{2}$	
$^{h}>3$, $^{h}>4$	

Elevator full up, ailerons full with (top right box):

48	5D
39 (128)	0.47 (2.1)
1, 1, $1\frac{1}{4}$	

Ailerons full against (Stick left):

o

33 42	7U 1U
40 (130)	0.42 (2.4)
56 (185)	0.56 (1.8)
$^{p}\frac{1}{2}$, $^{p}\frac{3}{4}$, q_1, $^{q}1\frac{1}{2}$	

Ailerons full with (Stick right):

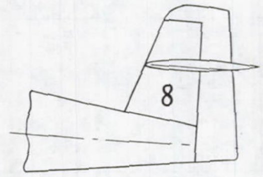
39	5D
43 (140)	0.53 (1.9)
$\frac{3}{4}$, 1, 1	

Elevator full down (Stick forward)

α' deg	φ deg
V m/sec (fps)	Ω rps (sec/rev)
Turns for recovery	

CHART 8.- Continued

(b) Effect of ventral fins



Low-wing model A
Right erect spins
Weight, 6672 N (1500 lb)
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Center of gravity at $0.255\bar{c}$
Altitude, 3000 m (10 000 ft)

R, right
L, left
W, with
A, against
U, inner wing up
D, inner wing down

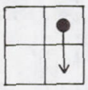
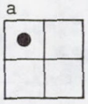
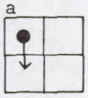
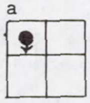
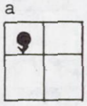
Spin block	Spin characteristics: α', deg	Spin characteristics: φ, deg	Spin characteristics: V, m/sec (ft/sec)	Spin characteristics: Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
No ventral fin								
	45	2U 1D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / -	8.3W / -	$\frac{3}{4}$, 1, 1
	45	2U 1D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / 10D	8.3W / -	1, $1\frac{1}{4}$, $1\frac{1}{4}$
	45	2U 1D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / 0	8.3W / -	1, $1\frac{1}{4}$, $1\frac{1}{2}$
	45	2U 1D	40 (130)	0.46 (2.2)	25W / 0	16.7U / 0	8.3W / -	>3, >4
a 	44	2U 7D	40 (130)	0.42 (2.4)	25W / 16.7A	16.7U / -	8.3A / -	$\frac{1}{2}$, $\frac{3}{4}$
	37	4D	48 (159)	0.37 (2.7)				$\frac{3}{4}$
a 	44	2U 7D	40 (130)	0.42 (2.4)	25W / 16.7A	16.7U / 10D	8.3A / -	1, $1\frac{1}{4}$
	37	4D	48 (159)	0.37 (2.7)				-
a 	44	2U 7D	40 (130)	0.42 (2.4)	25W / 16.7A	16.7U / 0	8.3A / -	1, 1
	37	4D	48 (159)	0.37 (2.7)				-
a 	44	2U 7D	40 (130)	0.42 (2.4)	25W / 0	16.7U / 0	8.3A / -	$>3\frac{1}{2}$
	37	4D	48 (159)	0.37 (2.7)				$>2\frac{1}{2}$

CHART 8.- Continued

(b) Concluded

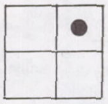
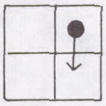
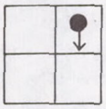
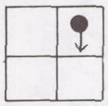
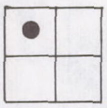
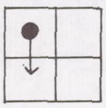
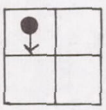
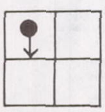
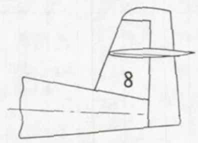
Spin block	Spin characteristics: α', deg	φ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	Turns for recovery
Ventral fin 1								
	41	4D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / -	8.3W / -	$\frac{3}{4}$, $\frac{3}{4}$
	41	4D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / 10D	8.3W / -	$1\frac{1}{4}$, $1\frac{1}{4}$
	41	4D	40 (130)	0.46 (2.2)	25W / 16.7A	16.7U / 0	8.3W / -	$1\frac{1}{4}$, $1\frac{1}{2}$, >2
	41	4D	40 (130)	0.46 (2.2)	25W / 0	16.7U / 0	8.3W / -	>2, >2
	37	2U 3D	48 (159)	0.39 (2.6)	25W / 16.7A	16.7U / -	8.3A / -	$\frac{1}{4}$, $\frac{1}{4}$
	37	2U 3D	48 (159)	0.39 (2.6)	25W / 16.7A	16.7U / 10D	8.3A / -	$\frac{1}{2}$
	37	2U 3D	48 (159)	0.39 (2.6)	25W / 16.7A	16.7U / 0	8.3A / -	$\frac{1}{2}$, 1
	37	2U 3D	48 (159)	0.39 (2.6)	25W / 0	16.7U / 0	8.3A / -	>3

CHART 8.- Concluded

(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	Flaps	Altitude	Center-of-gravity position
8	0^o	3000 m (10 000 ft).	$0.145\bar{c}$



Model values converted to full scale

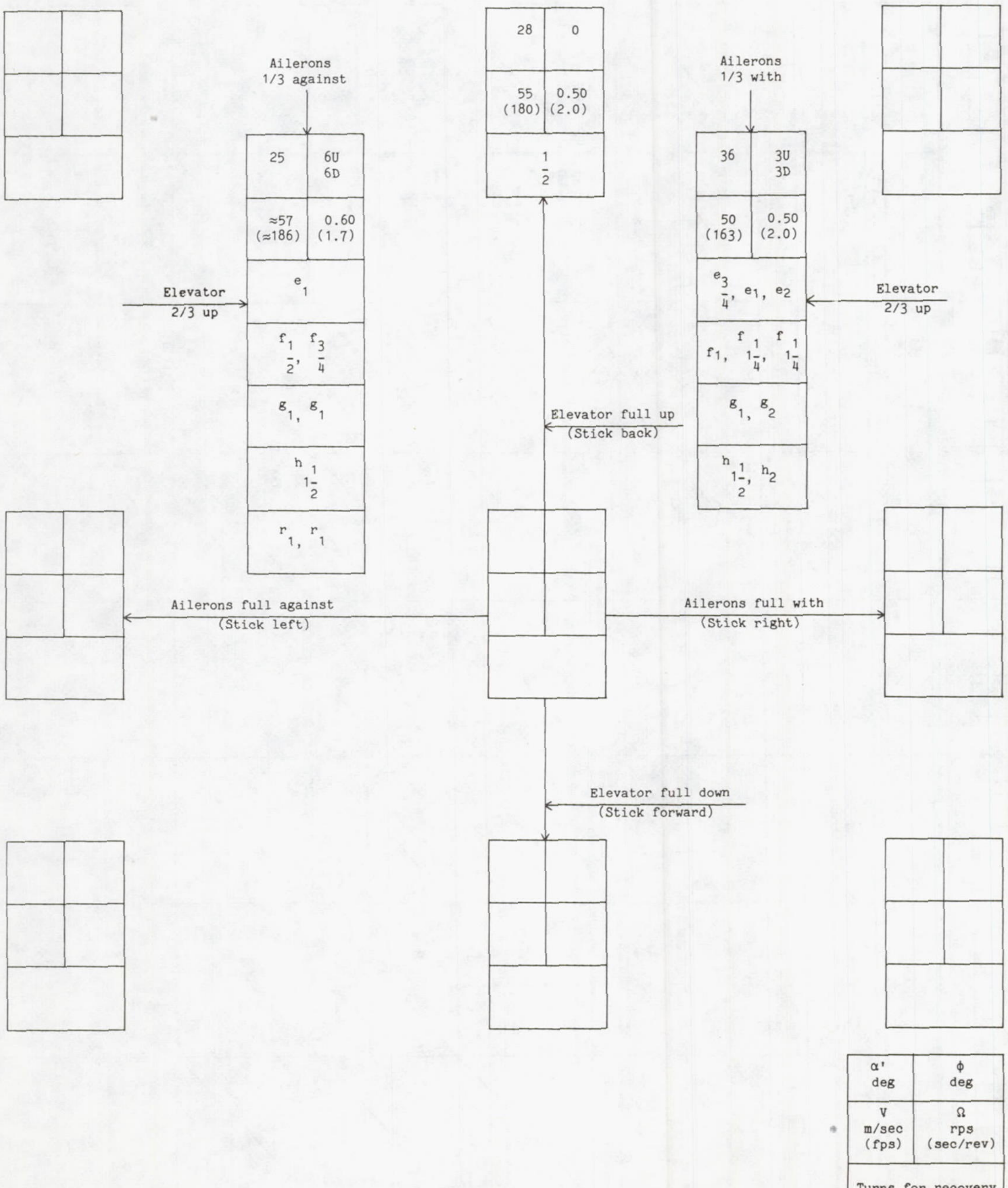
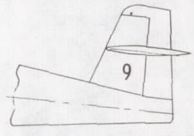


CHART 9.- SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH TAIL 9

(a) Spin characteristics for aft center of gravity

[Recovery attempted by full rudder reversal unless *otherwise* noted (*recovery* attempted *from* and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	Flaps	Altitude	Center-of-gravity position
9	0°	3000 m (10 000 ft)	$0.255\bar{c}$



Model values converted to full scale

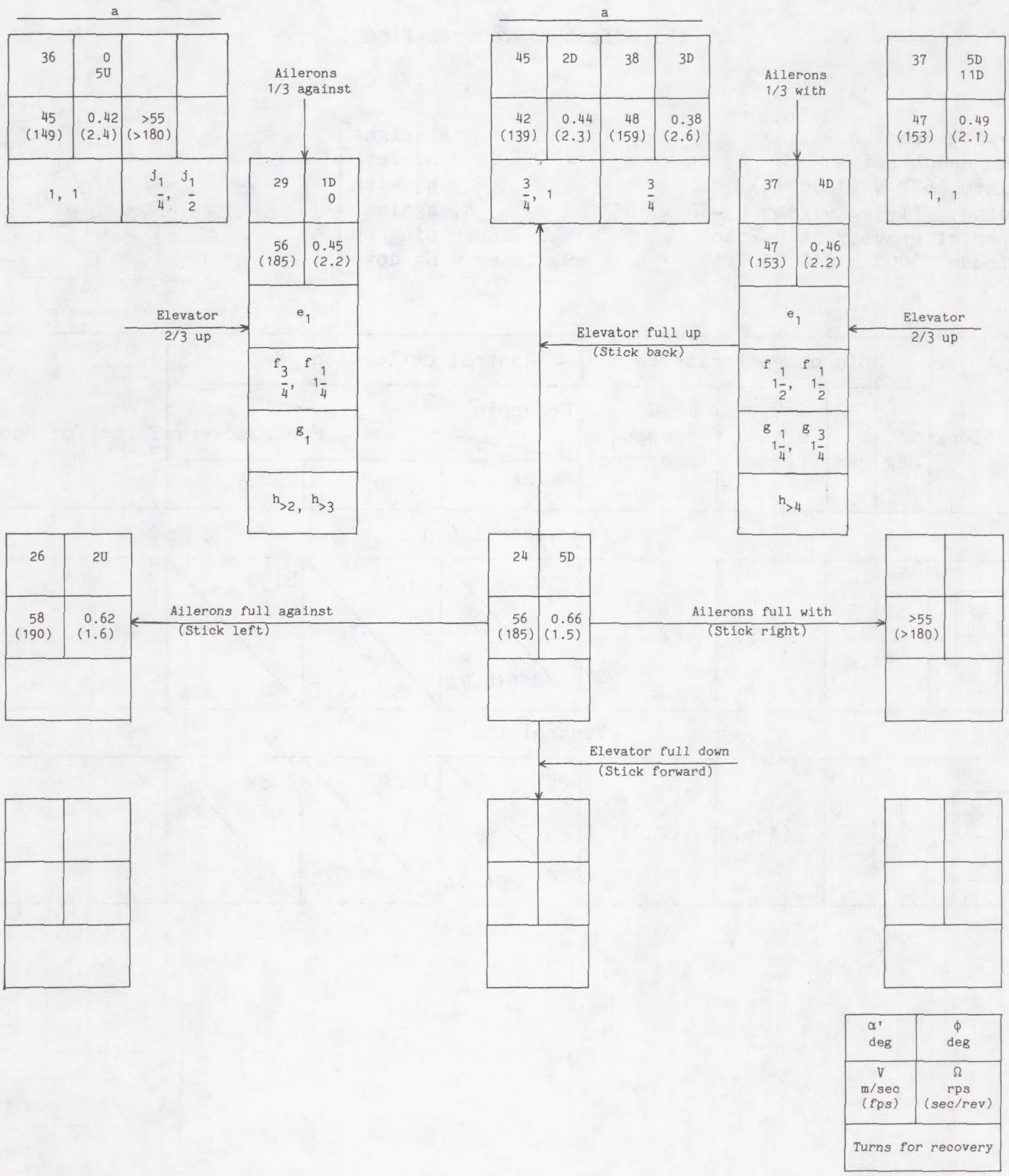
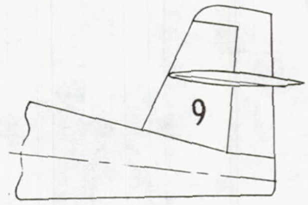


CHART 9.- Continued

(b) Effect of ventral fins

Low-wing model A
Right erect spins
Weight, 6672 N (1500 lb)
Loading, $(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Center of gravity at $0.255\bar{c}$
Altitude, 3000 m (10 000 ft)

R, right
L, left
W, with
A, against
U, inner wing up
D, inner wing down



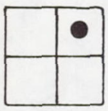
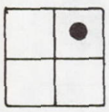
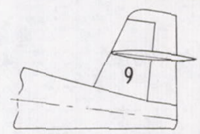
Spin block	Spin characteristics				Control deflection, deg (For spin / For recovery)			Turns for recovery
	α', deg	φ, deg	V, m/sec (ft/sec)	Ω, rps (sec/turn)	δ_r	δ_e	δ_a	
No ventral fin								
	37	4D	47 (153)	0.46 (2.2)	25W / 16.7A	16.7U / -	8.3W / -	1
Ventral fin 1								
	40	4D	45 (146)	0.45 (2.2)	25W / 16.7A	16.7U / -	8.3W / -	1,1

CHART 9.- *Concluded*

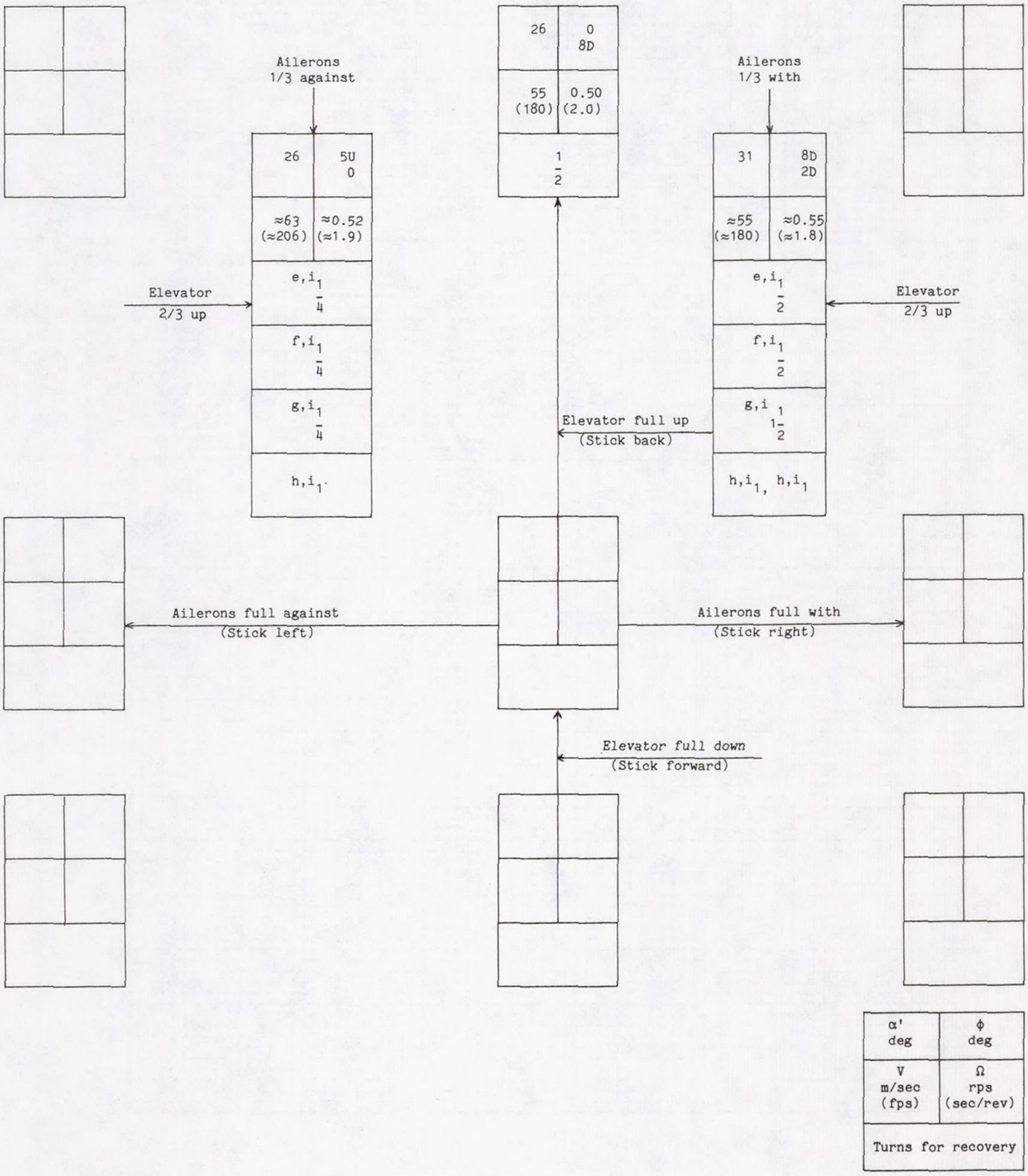
(c) Spin characteristics for forward center of gravity

[Recovery attempted by full rudder reversal unless otherwise noted (recovery attempted from and developed spin data presented for rudder-full-with spins); U, inner wing up; D, inner wing down]

Model	Attitude	Direction	Loading
Low-wing Model A	Erect	Right	$(I_X - I_Y)/mb^2 = -50 \times 10^{-4}$
Tail	**Flaps**	**Altitude**	**Center-of-gravity position**
9	0°	3000 m (10 000 ft)	$0.145\bar{c}$



Model values converted to full scale



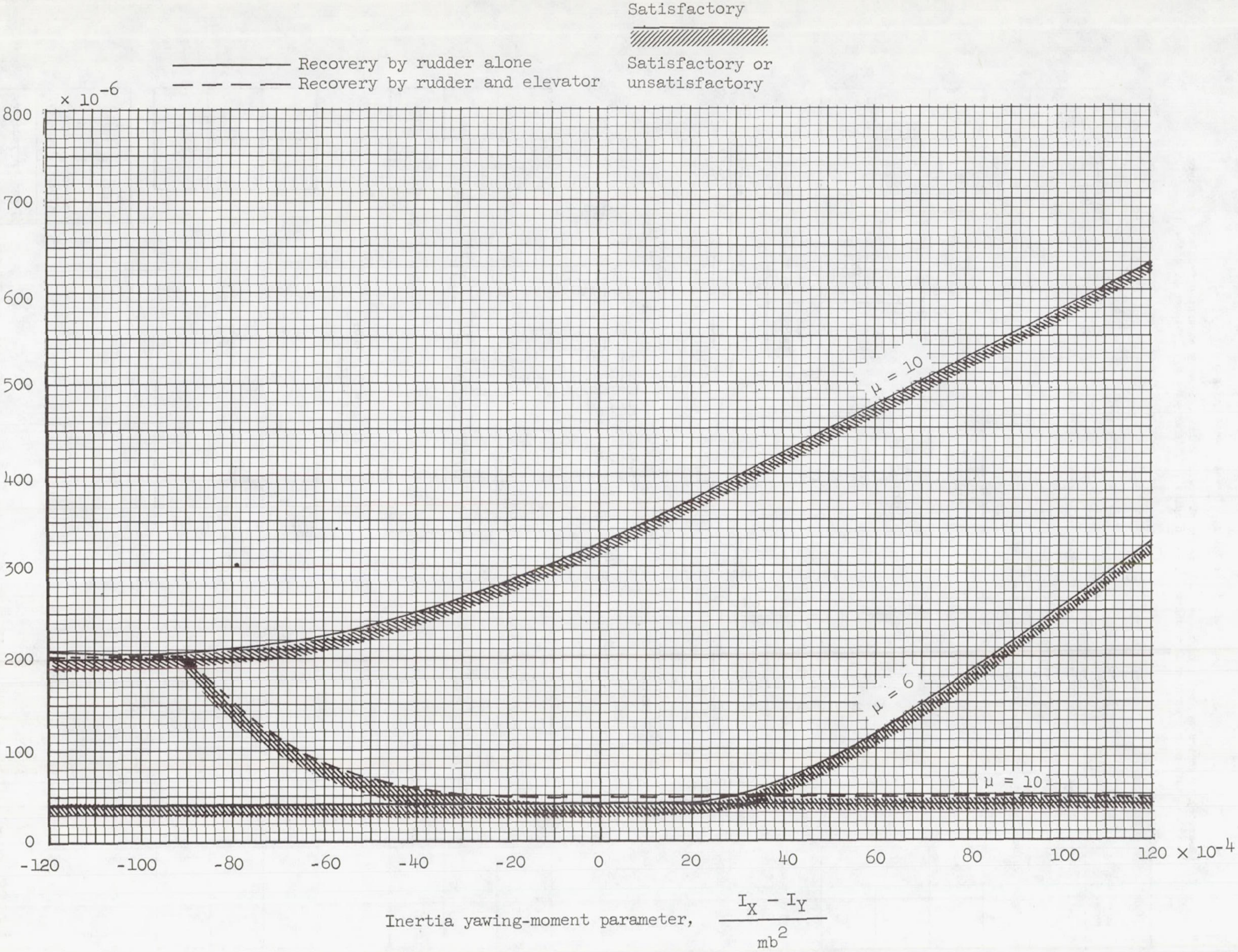


Figure 1.- Boundaries for existing tail design criterion for airplanes having relative density factors of 6 and 10 (ref. 18).

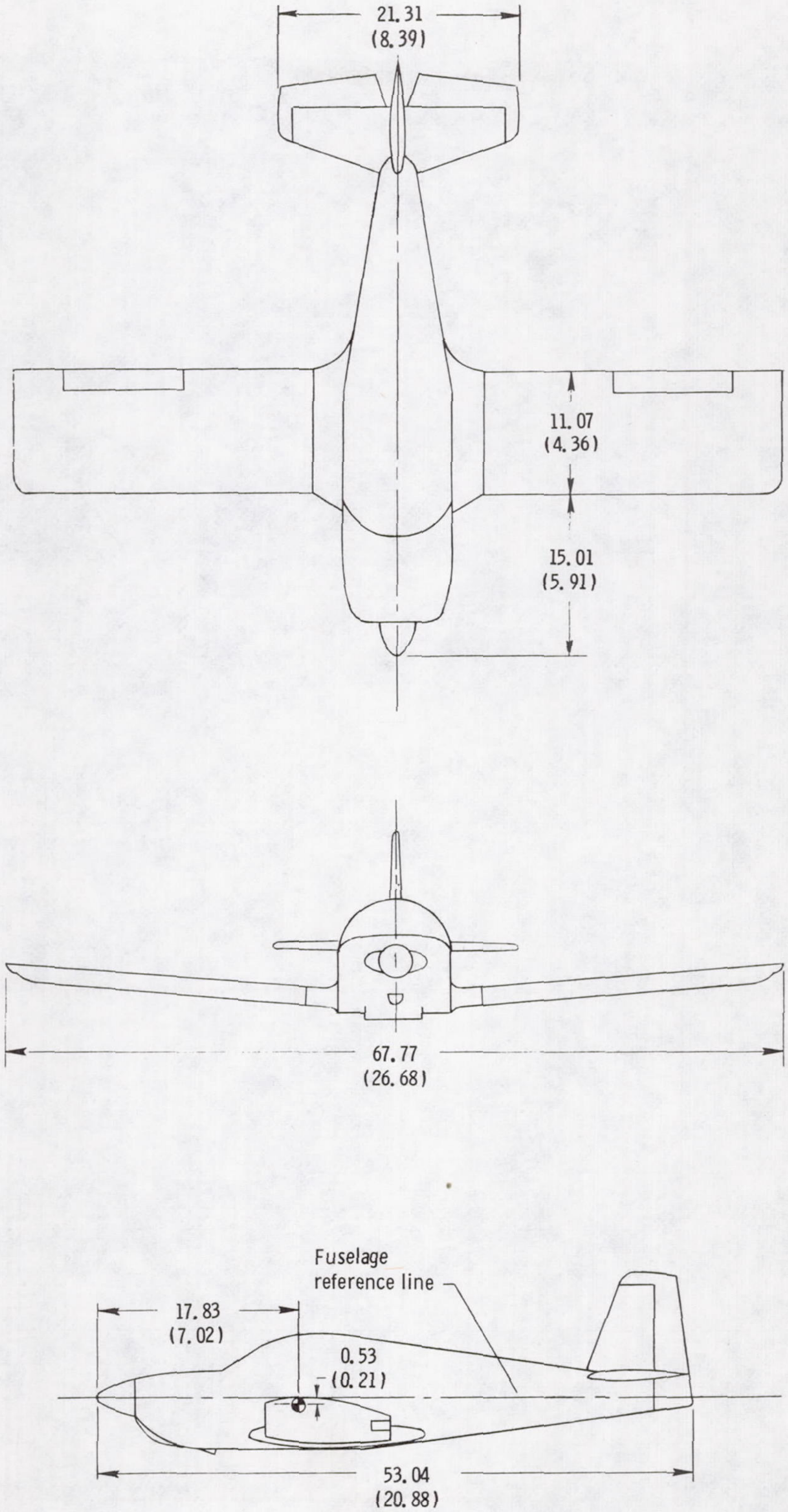
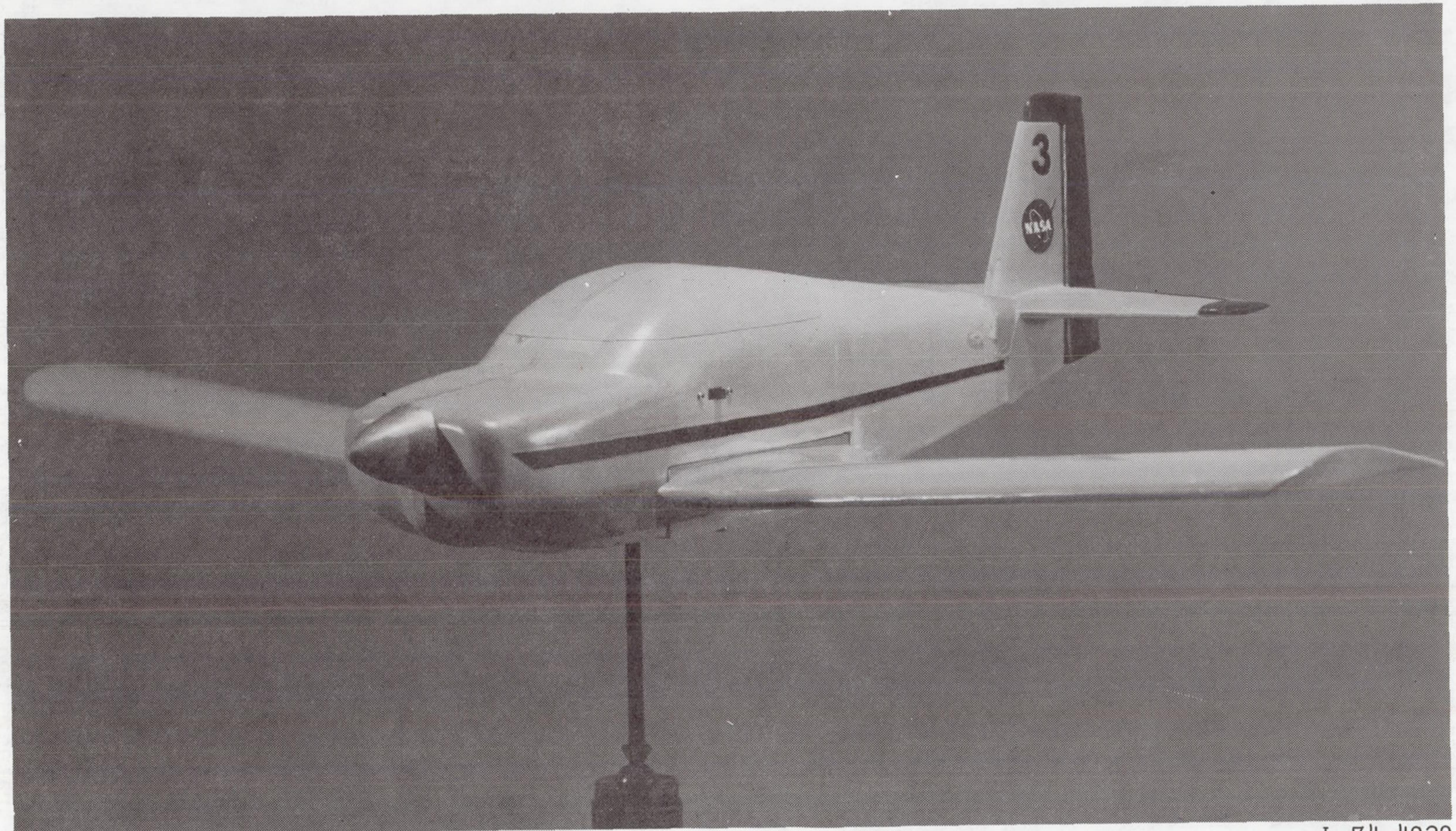
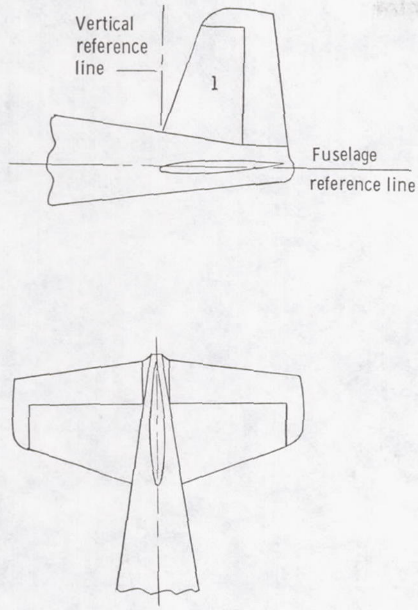


Figure 2.- Three-view drawing of 1/11-scale model tested with tail 3 illustrated. Center-of-gravity position at $0.255\bar{c}$. Dimensions are given in centimeters (inches), model scale.

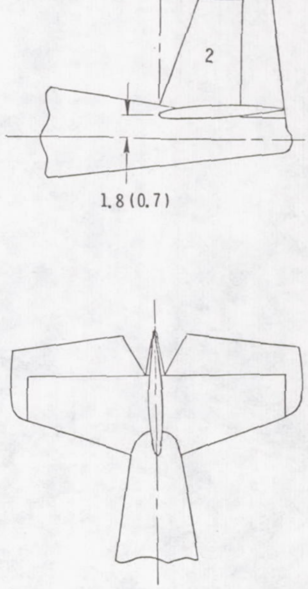


L-74-4920

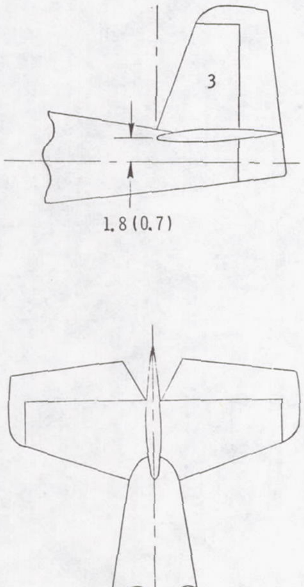
Figure 3.- Model with tail 3 installed.



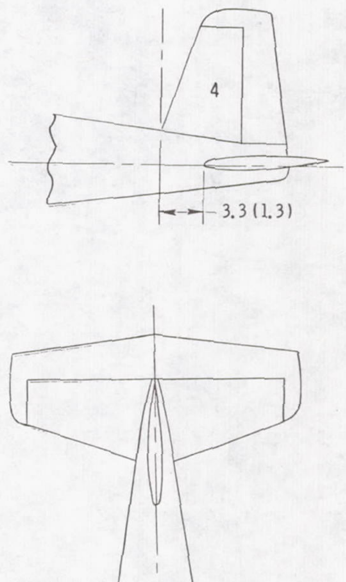
(a) Tail 1.



(b) Tail 2.

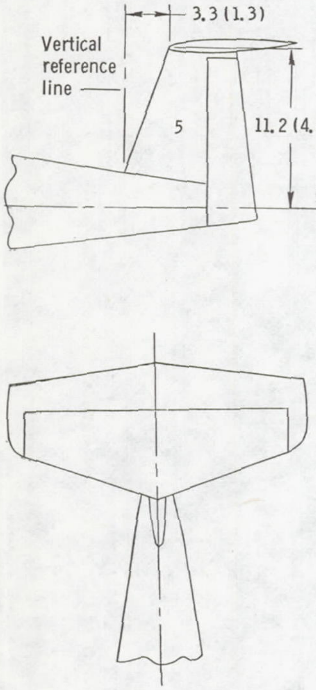


(c) Tail 3.

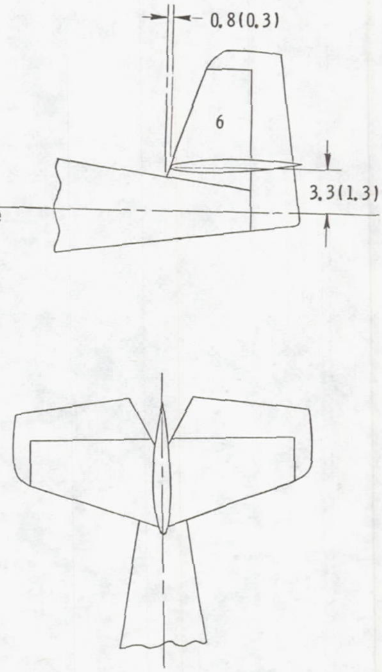


(d) Tail 4.

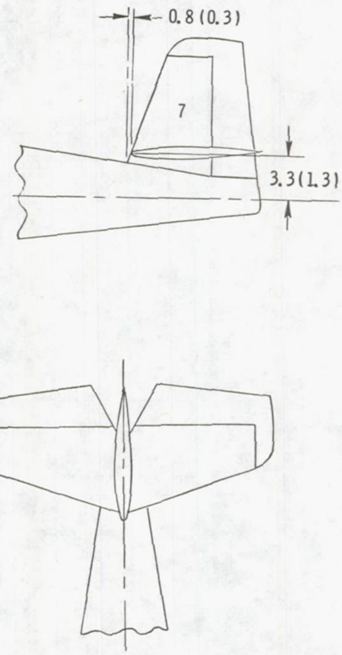
Figure 4.- Tail configurations tested on model. Dimensions are given in centimeters (inches), model scale.



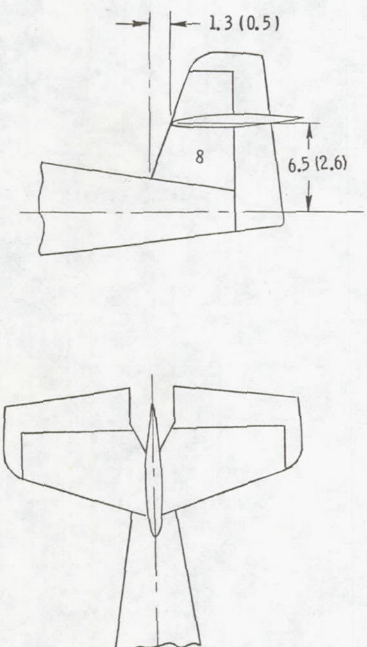
(e) Tail 5.



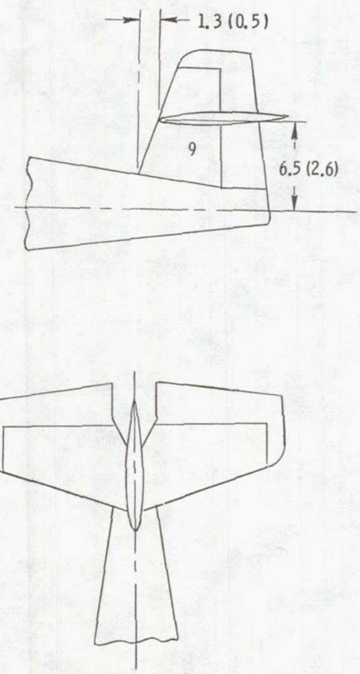
(f) Tail 6.



(g) Tail 7.

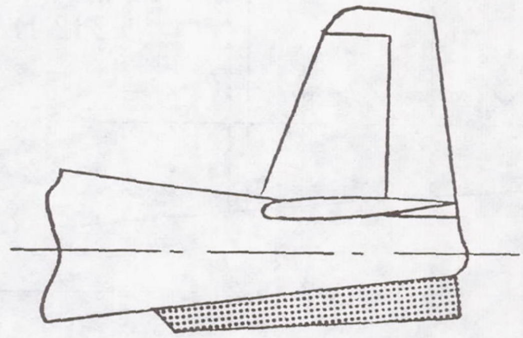


(h) Tail 8.

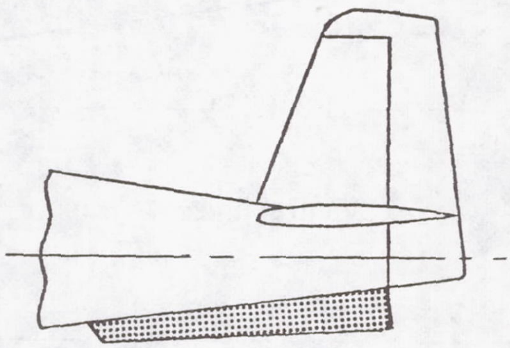


(i) Tail 9.

Figure 4.- Concluded.



(a) Partial-span rudder.



(b) Full-span rudder.

Figure 5.- Typical locations of ventral fins on tail configurations having partial- and full-span rudders.

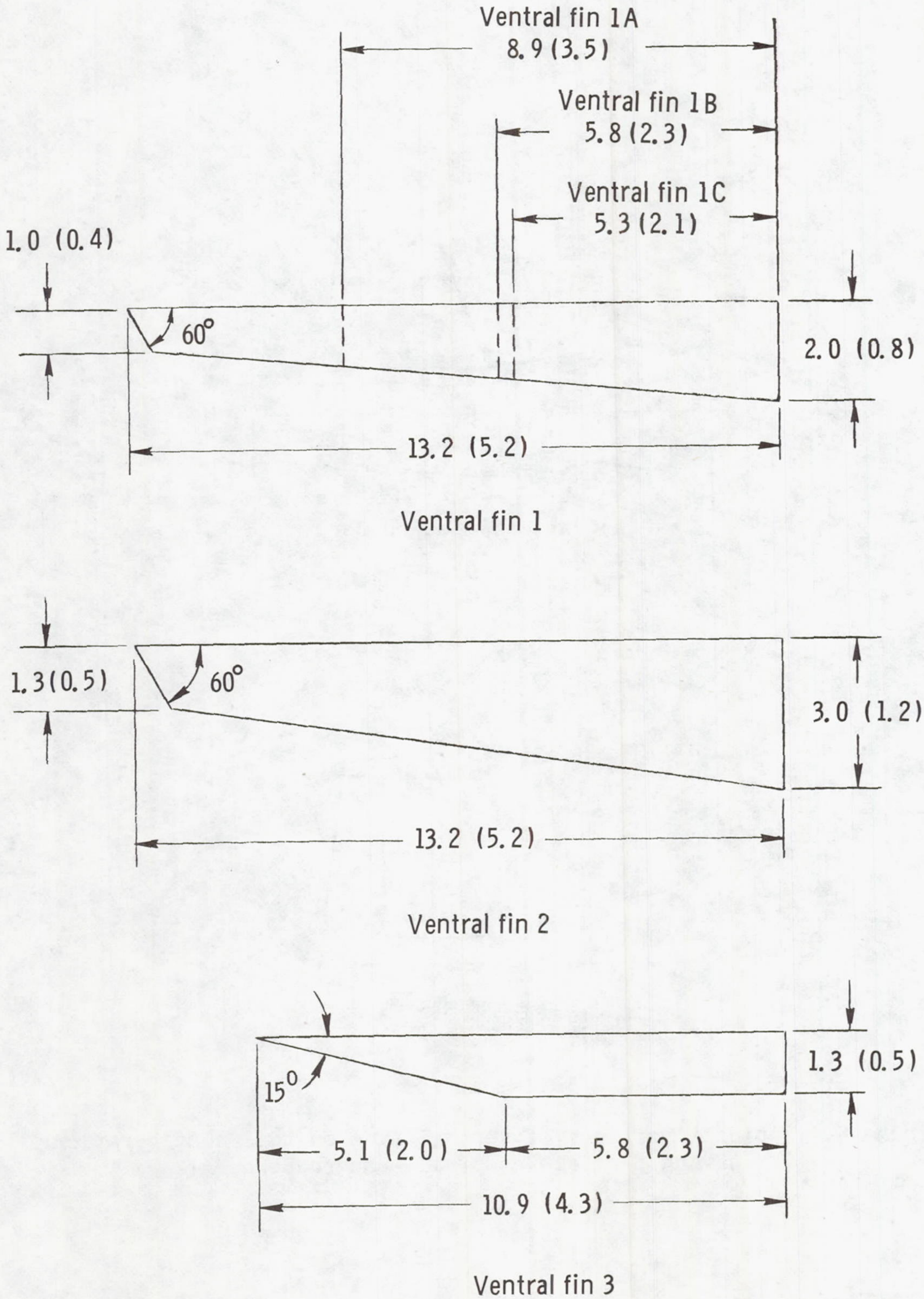
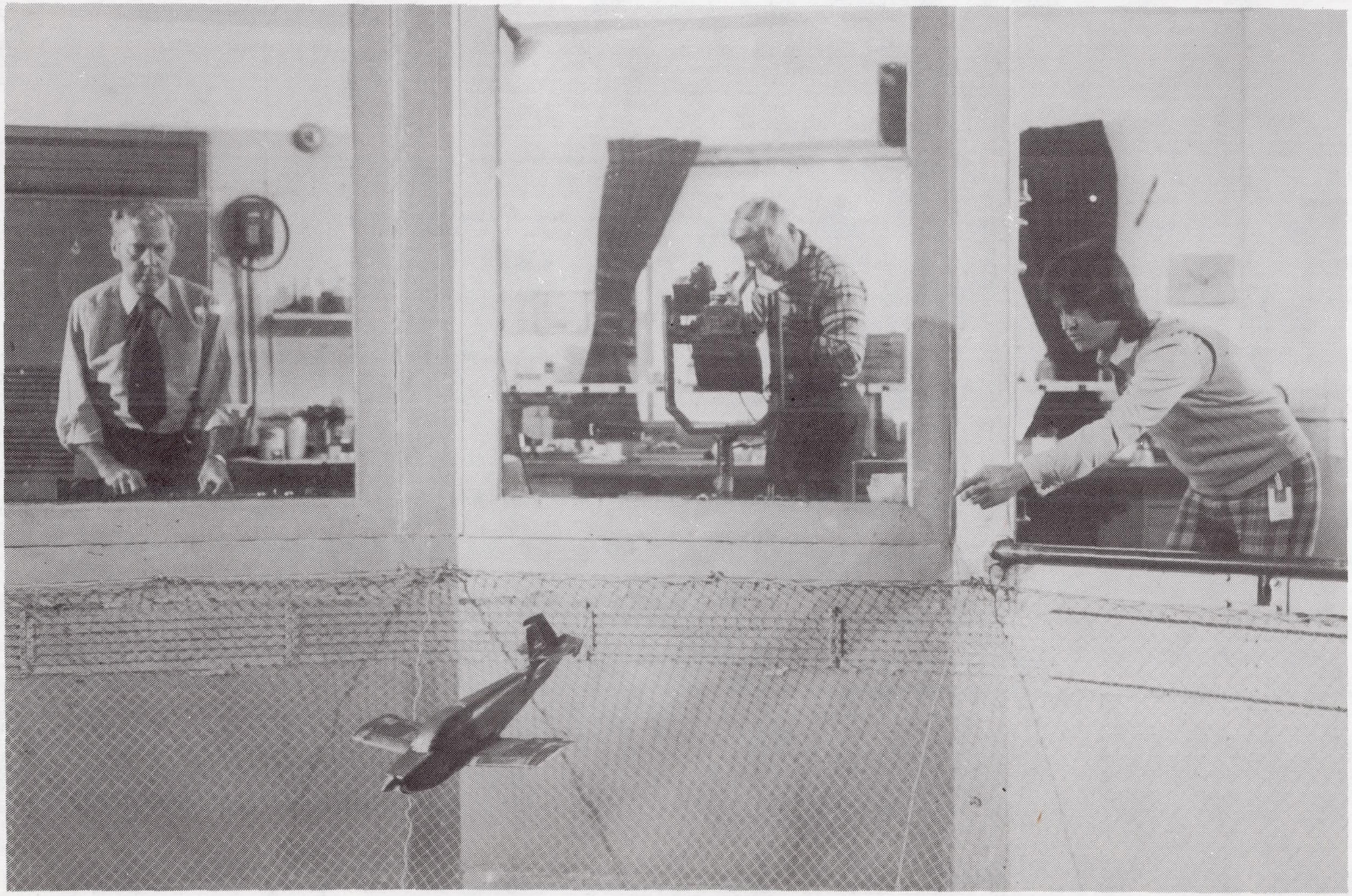


Figure 6.- Ventral fins tested on model. Dimensions are given in centimeters (inches), model scale.



L-74-1858

Figure 7.- Model being tested in Langley spin tunnel.

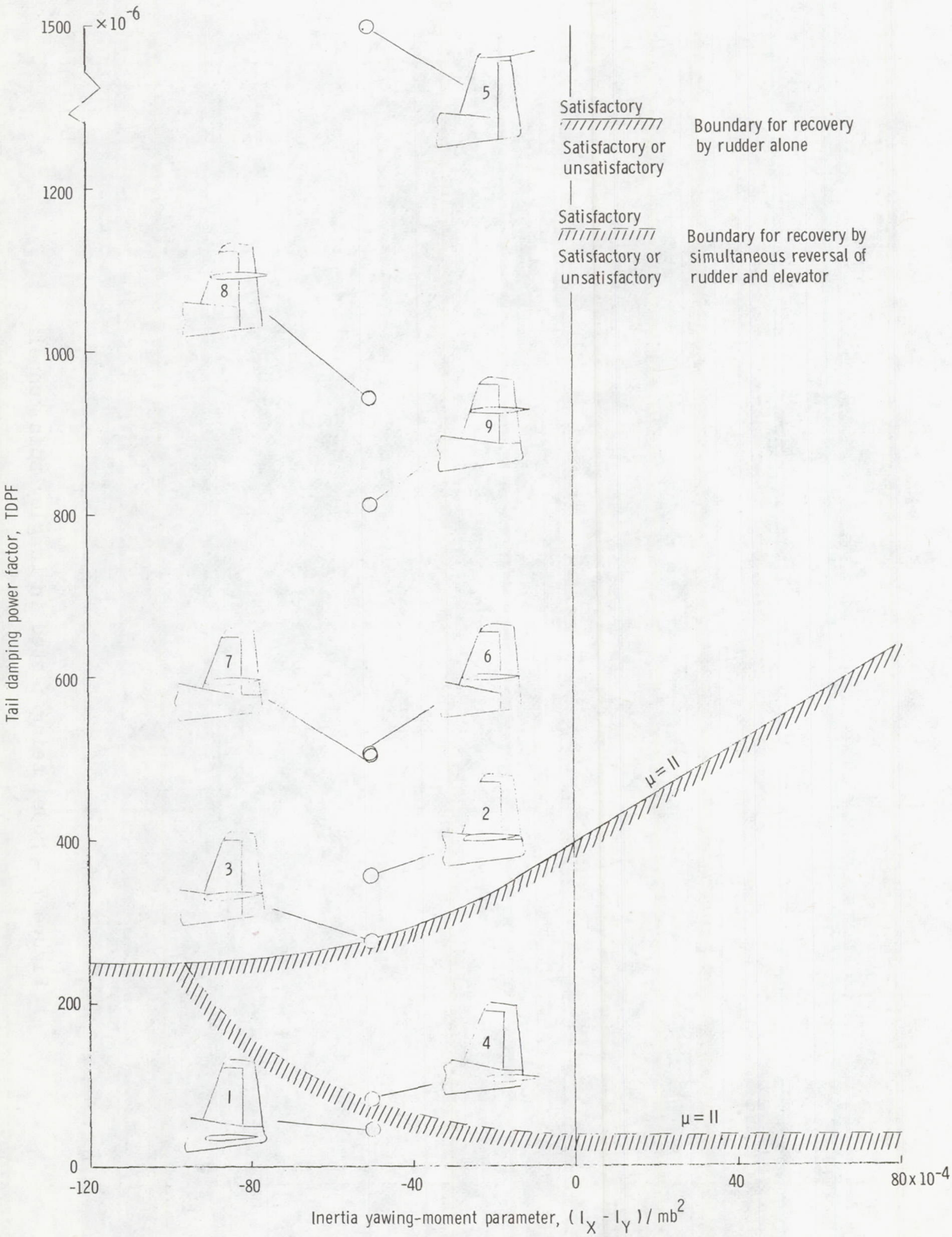


Figure 8.- Locations of tail configurations on tail design criterion chart for spin recovery.

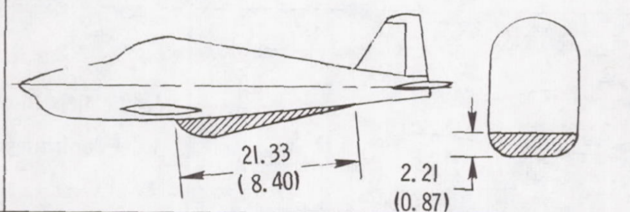
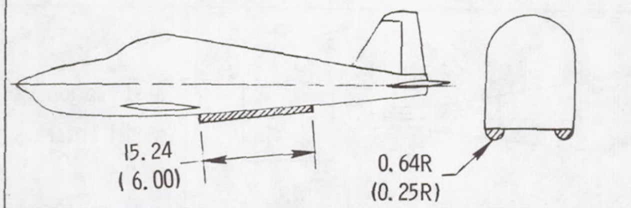
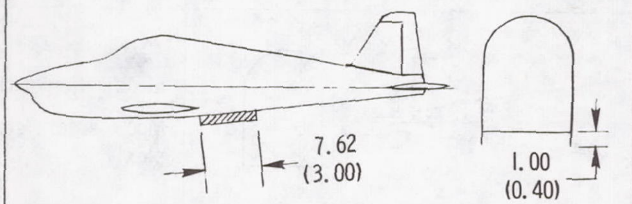
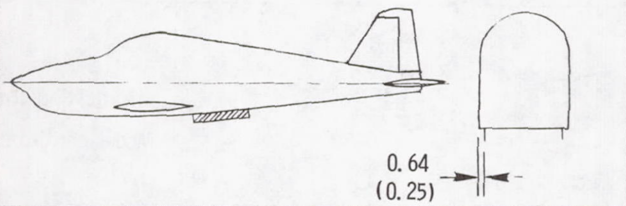
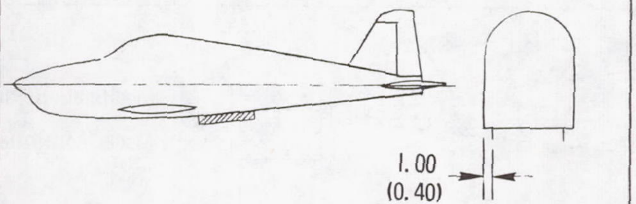
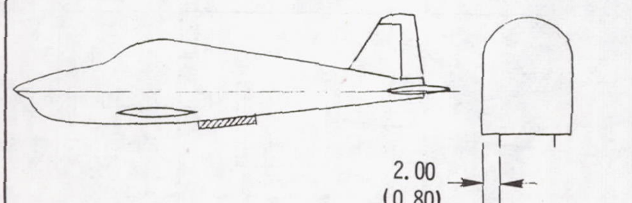
Modification	Modification Location	Modification Effects on Spin Characteristics
Rounded fuselage bottom		Modification very effective Model enters steep spin quickly
Rounded fuselage corners		Modification ineffective Model continues to spin flat
Fins on fuselage bottom		Modification ineffective Model continues to spin flat
Fins on fuselage bottom		Modification very effective Model enters steep spin quickly
Fins on fuselage bottom		Modification effective Model enters steep spin slowly
Fins on fuselage bottom		Modification ineffective Model continues to spin flat

Figure 9.- Results of fuselage modifications to prevent flat-spin conditions. Dimensions are in centimeters (inches), model scale. Model launched flat in right spin for all tests. Center of gravity at $0.255\bar{c}$.

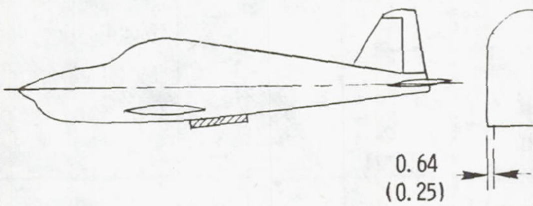
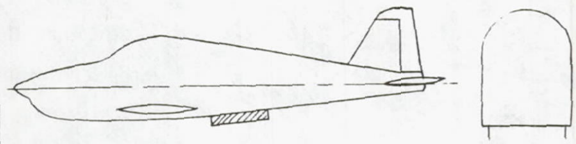
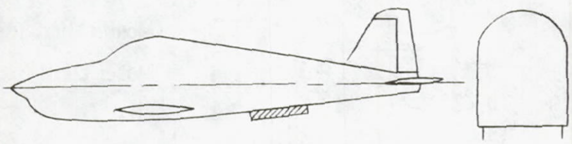
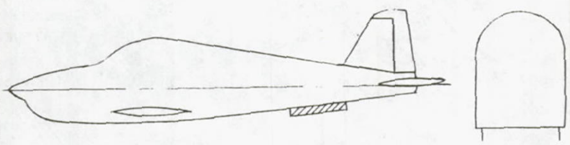
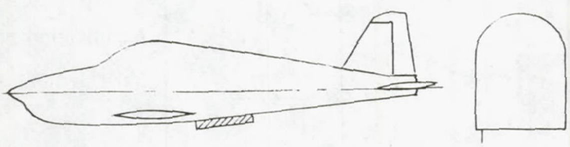
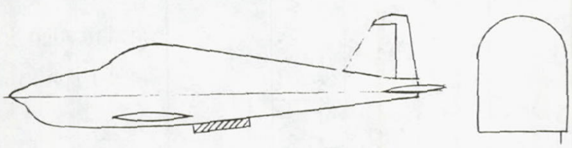
<table>
<tr><th>Modification</th><th>Modification Location</th><th>Modification Effects on Spin Characteristics</th></tr>
<tr><td>Fins on fuselage bottom</td><td>
</td><td>Modification ineffective
Model continues to spin flat</td></tr>
<tr><td>Fins on fuselage bottom</td><td></td><td>Modification very effective
Model enters steep spin quickly</td></tr>
<tr><td>Fins on fuselage bottom</td><td></td><td>Modification partially effective
Model enters steep spin very slowly</td></tr>
<tr><td>Fins on fuselage bottom</td><td></td><td>Modification ineffective
Model continues to spin flat</td></tr>
<tr><td>Single fin on fuselage bottom</td><td></td><td>Modification ineffective
Model continues to spin flat</td></tr>
<tr><td>Single fin on fuselage bottom</td><td></td><td>Modification very effective
Model enters steep spin quickly</td></tr>
</table>

Figure 9.- Continued.

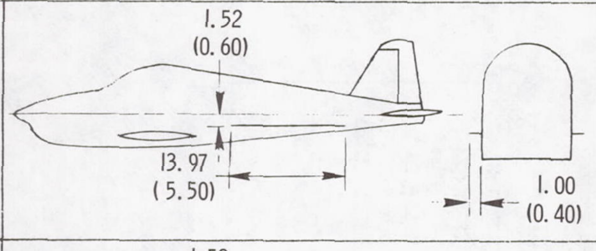
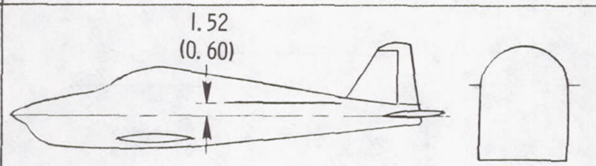
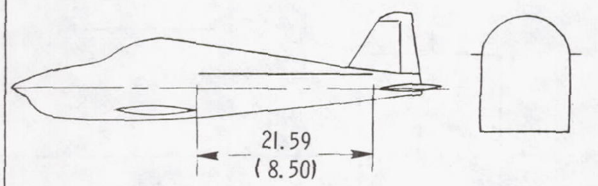
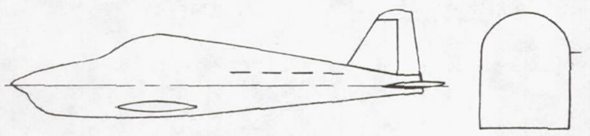
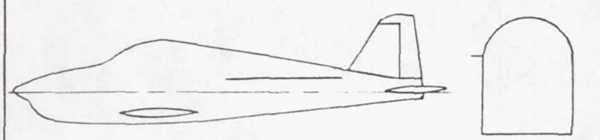
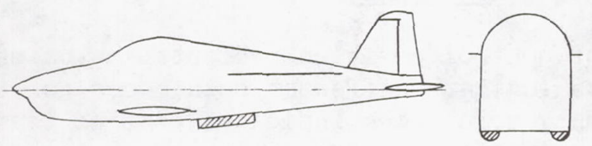
Modification	Modification Location	Modification Effects on Spin Characteristics
Strakes		Modification ineffective Model continues to spin flat
Strakes		Modification only slightly effective Model enters moderate flat spin
Strakes		Modification only slightly effective Model enters moderate flat spin
Single strake		Modification ineffective Model continues to spin flat
Single strake		Modification only slightly effective Model enters moderate flat spin
Strakes and rounded fuselage corners		Modification effective Model enters steep spin slowly

Figure 9.- Concluded.

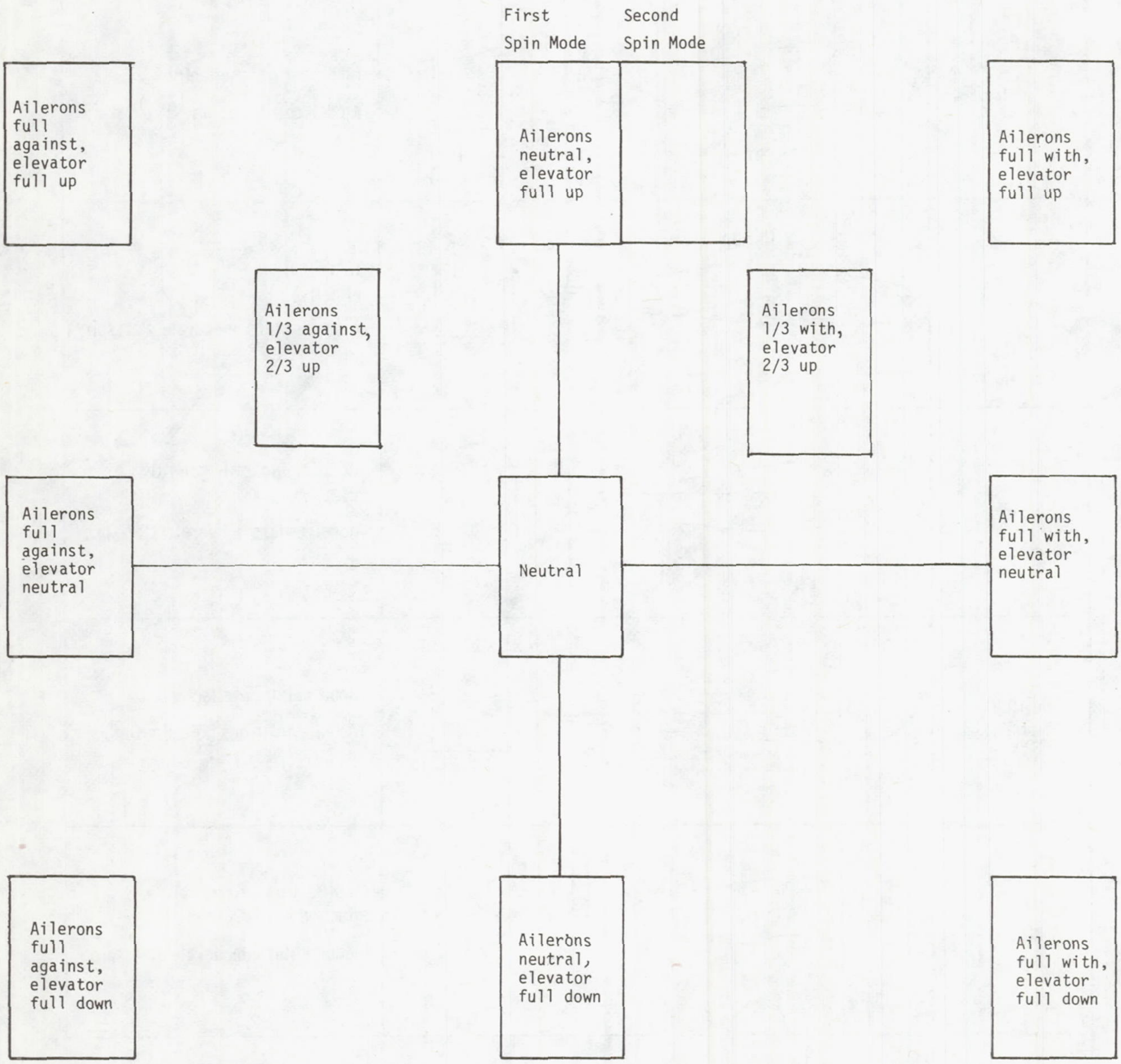
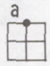
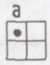
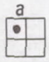
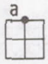
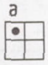
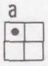


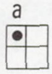
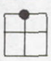
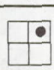
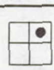
Figure 10.- Illustration of control position presentation on spin charts. Side-by-side spin blocks indicate different spin modes for the same control setting. An empty spin block indicates that no tests were conducted for that control position. Movements of controls for recovery are indicated by footnotes. Each recovery listed indicates a different recovery attempted.

Tail configuration	Control setting for spin	Ventral fin 1	Spin mode	α', deg	Ω, rps (sec/turn)	Turns for recovery	Recovery characteristics
1	[a] 	Off	Flat	75	0.84 (1.2)	∞	Unsatisfactory
			Moderately flat	48	0.48 (2.1)	$1\frac{1}{2}, 1\frac{1}{2}, 1\frac{1}{2}$	
	[a] 	Off	Flat	79	0.94 (1.1)	∞	
			Moderately flat	46	0.46 (2.2)	$2\frac{1}{2}, 3, 3\frac{1}{2}$	
	[a] 	On	Flat	75	0.79 (1.3)	∞	
			Moderately flat	48	0.45 (2.2)	$1\frac{3}{4}, 2\frac{1}{2}, 2\frac{1}{2}$	
2		Off	Moderately flat	45	0.40 (2.5)	1, 1, 2	Unsatisfactory
		Off	Moderately flat	47	0.46 (2.2)	$2, 2\frac{1}{4}, 3$	
		On	Steep	–	–	[b] $\frac{1}{2}$	
3	[a] 	Off	Flat	80	0.75 (1.3)	$5\frac{1}{2}, 7\frac{1}{2}$	Unsatisfactory
			Moderately flat	52	0.50 (2.0)	$1, 1, 1\frac{1}{4}$	
	[a] 	Off	Flat	81	0.79 (1.3)	∞	
			Moderately flat	52	0.50 (2.0)	$2, 2\frac{1}{4}, 3$	
		On	Moderately flat	55	0.54 (1.9)	$1\frac{1}{2}, 2\frac{1}{4}, 2\frac{1}{2}$	
4	[a] 	Off	Flat	77	0.90 (1.1)	∞	Unsatisfactory
			Moderately steep	38	0.40 (2.5)	$\frac{1}{2}, \frac{1}{2}, 1$	
	[a] 	Off	Flat	77	0.97 (1.0)	∞	
			Moderately steep	35	0.15 (2.2)	$1, 1\frac{1}{4}, 1\frac{1}{4}$	
		On	Steep	–	–	[b] $\frac{3}{4}$	

[a] Two conditions possible.

[b] Recovery attempted before final attitude reached.

Figure 11.- Summary of spin and recovery characteristics of model for normal and criterion spin control conditions. Recovery attempted by rudder alone. Center of gravity at $0.255\bar{c}$.

Tail configuration	Control setting for spin	Ventral fin 1	Spin mode	α', deg	Ω, rps (sec/turn)	Turns for recovery	Recovery characteristics
5		Off	Moderately flat	47	0.44 (2.3)	$\frac{1}{2}, \frac{3}{4}, 1$	Satisfactory
		Off	Moderately steep	41	0.44 (2.3)	$\frac{1}{2}, \frac{3}{4}, 1$	
		On	Moderately flat	47	0.42 (2.4)	$\frac{3}{4}, 1$	
6		Off	Moderately flat	53	0.48 (2.1)	$1, 1\frac{1}{4}, 1\frac{1}{2}$	Satisfactory
		Off	Moderately flat	55	0.52 (1.9)	$2, 2, 2\frac{1}{4}$	
		On	Moderately flat	53	0.50 (2.0)	$1\frac{3}{4}, 2\frac{1}{4}$	
7		Off	Moderately flat	48	0.44 (2.3)	$1\frac{1}{2}, 1\frac{3}{4}, 2\frac{1}{4}$	Unsatisfactory
		Off	Moderately flat	53	0.46 (2.2)	$3\frac{1}{4}, 3\frac{1}{2}, 4$	
	a 	On	Moderately steep	44	0.44 (2.3)	$1\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$	
			Steep	–	–	No recovery attempted	
8		Off	Moderately flat	48	0.45 (2.2)	$\frac{1}{2}, \frac{1}{2}, \frac{3}{4}$	Satisfactory
	a 	Off	Moderately steep	44	0.42 (2.4)	$\frac{1}{2}, \frac{3}{4}$	
			Moderately steep	37	0.37 (2.7)	$\frac{3}{4}$	
		On	Moderately steep	37	0.39 (2.6)	$\frac{1}{4}, \frac{1}{4}$	
9	a 	Off	Moderately flat	45	0.44 (2.3)	$\frac{3}{4}, 1$	
			Moderately steep	38	0.38 (2.6)	$\frac{3}{4}$	Satisfactory
		Off	Moderately steep	37	0.46 (2.2)	1	
		On	Moderately steep	40	0.45 (2.2)	1.1	

[a] Two conditions possible.

[b] Recovery attempted before final attitude reached.

Figure 11.- Concluded.

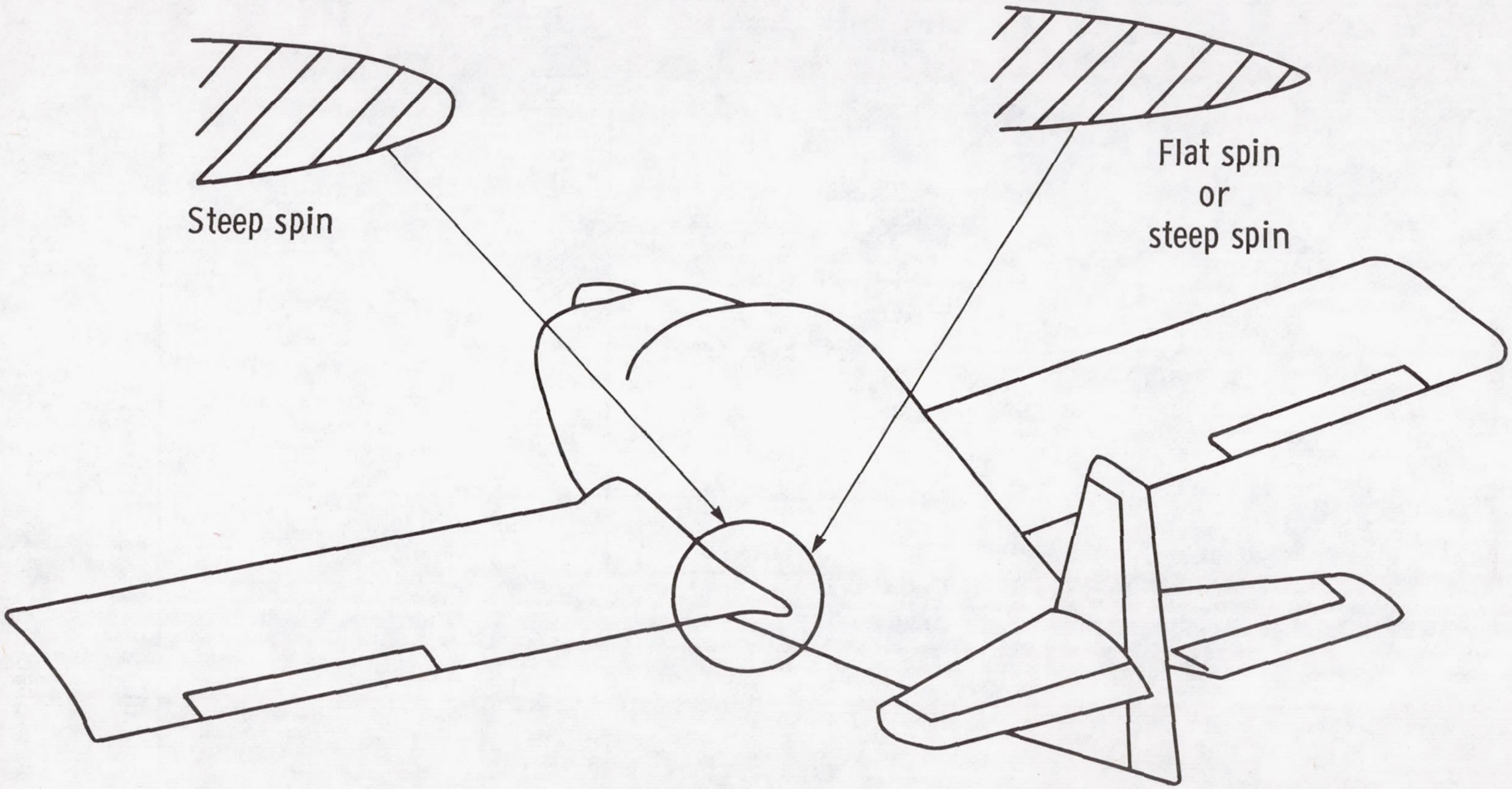


Figure 12.- Effect of trailing-edge wing fillet on spin for tail 3.

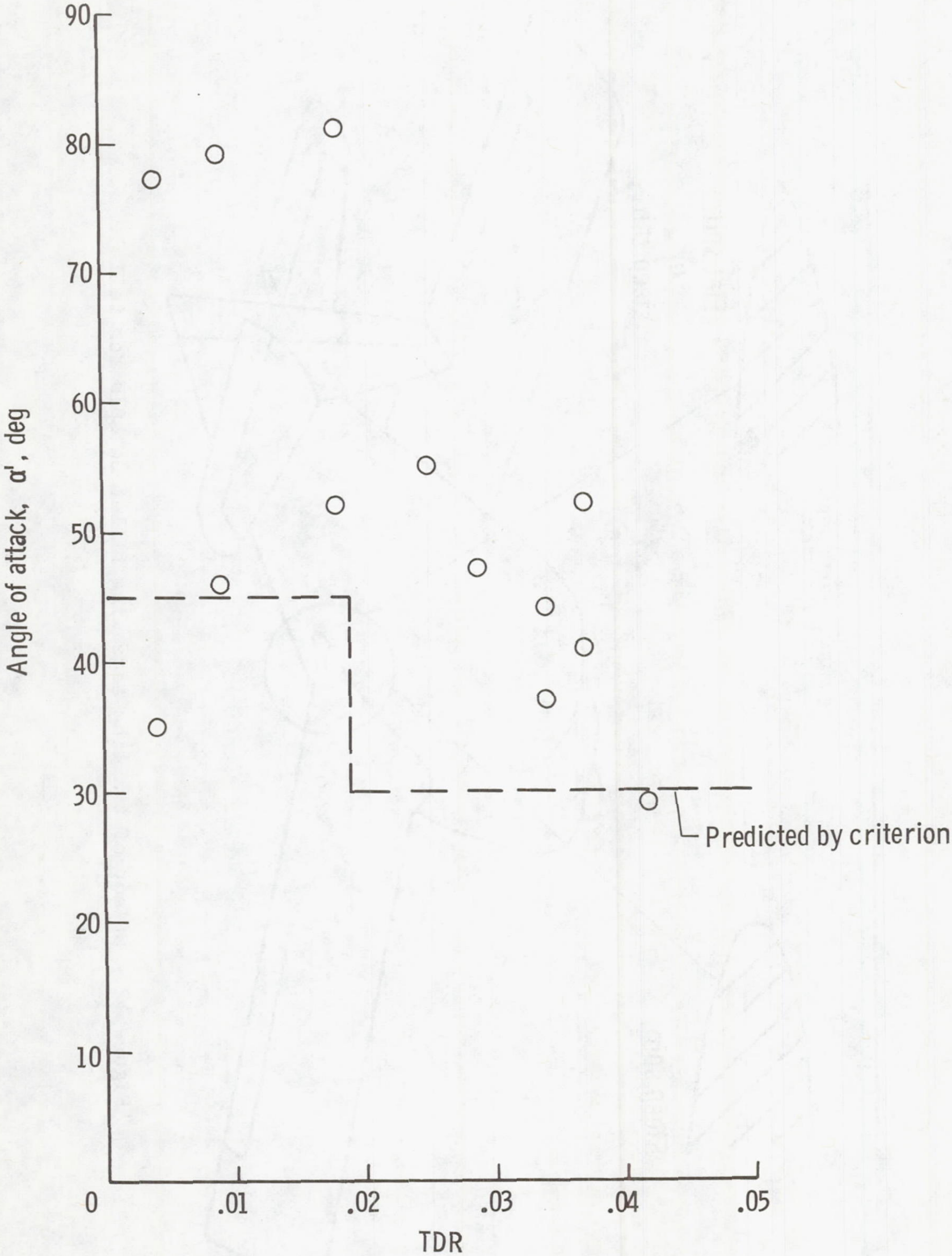
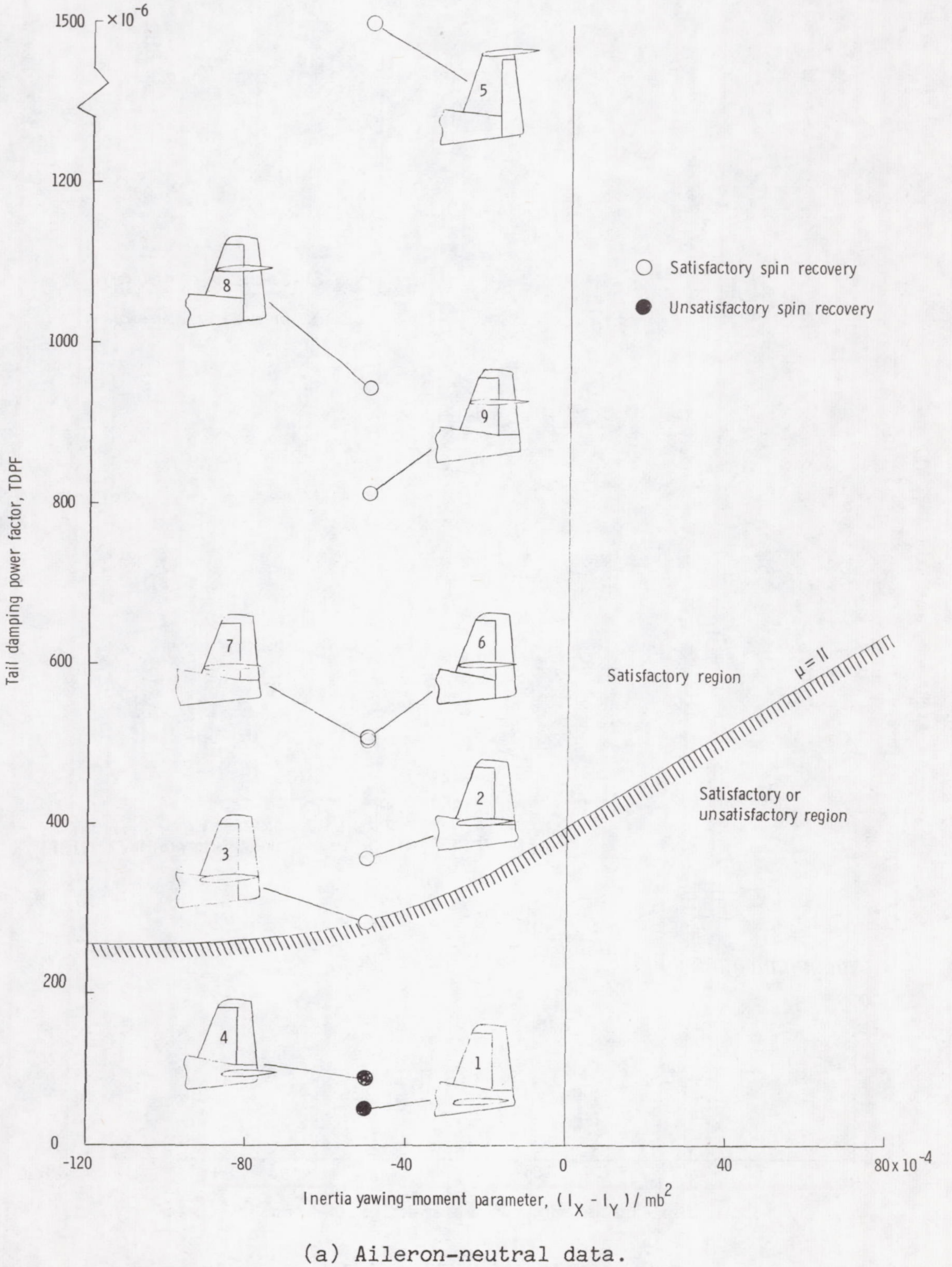
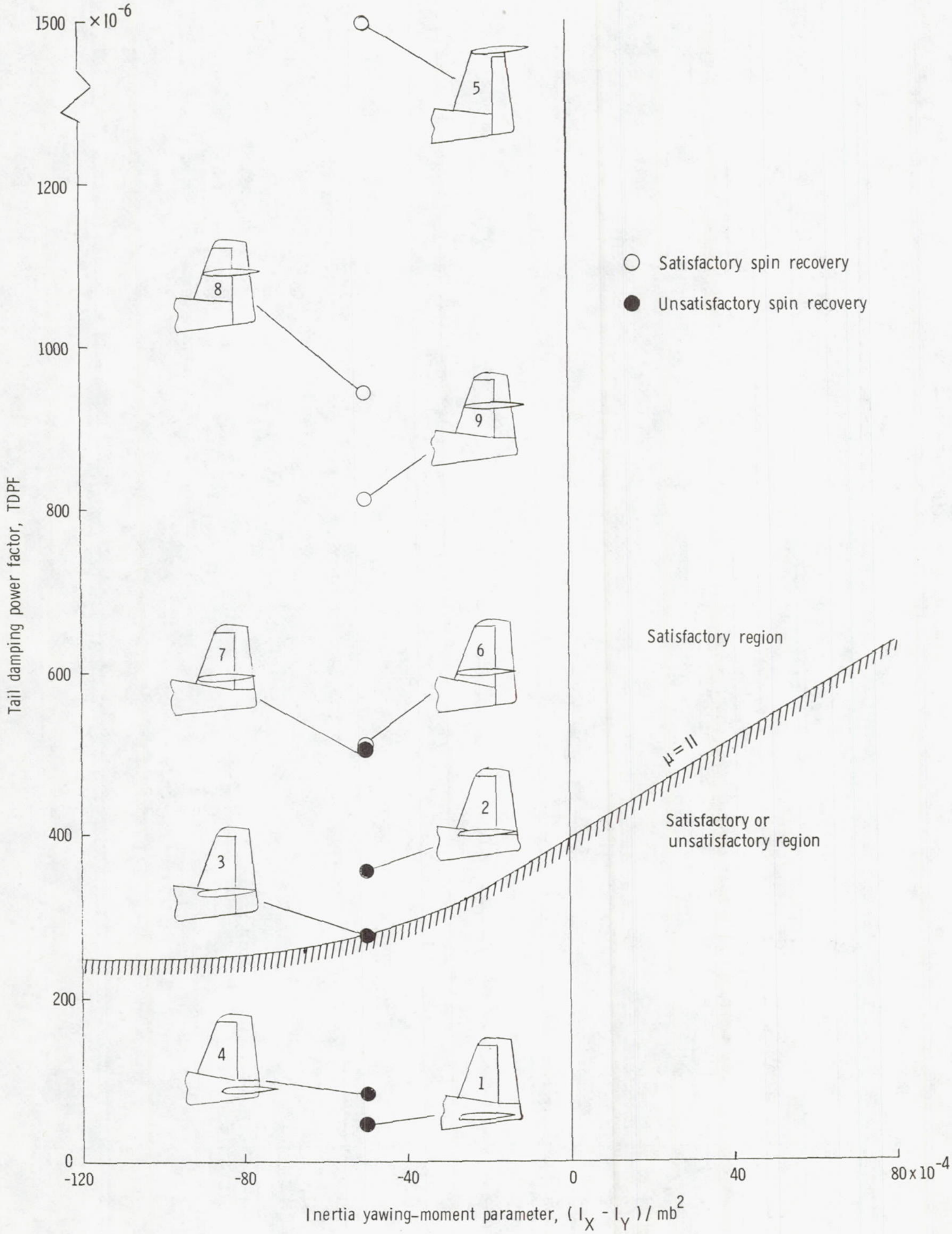


Figure 13.- Correlation of values of angle of attack obtained in tests with values predicted by the tail design criterion.



(a) Aileron-neutral data.

Figure 14.- Comparison of test results with tail design criterion. Recovery attempted by rudder alone.



(b) Aileron-deflected data.

Figure 14.- Concluded.

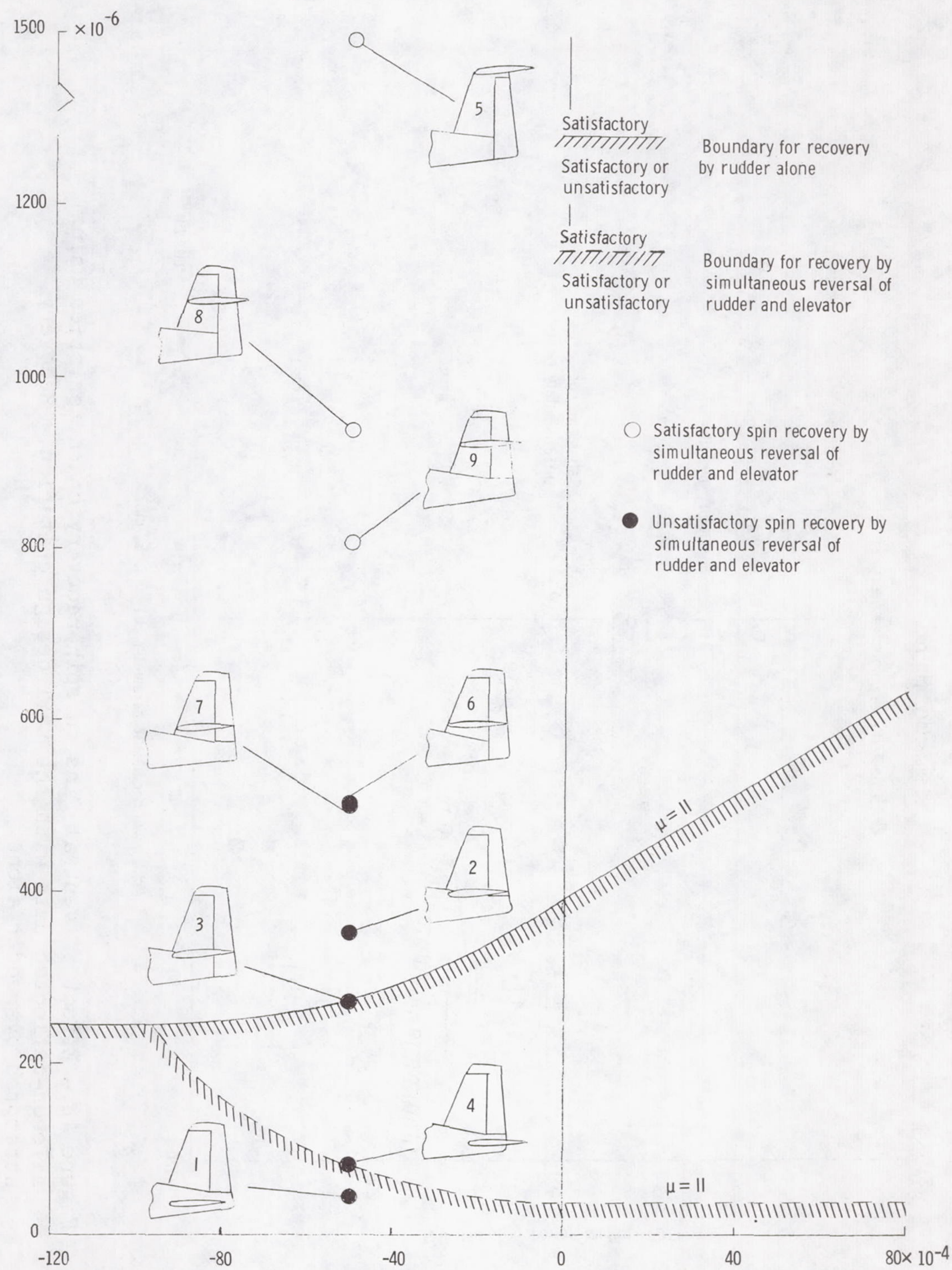


Figure 15.- Comparison of test results with tail design criterion using aileron-deflected data. Recovery attempted by simultaneous reversal of rudder and elevator.

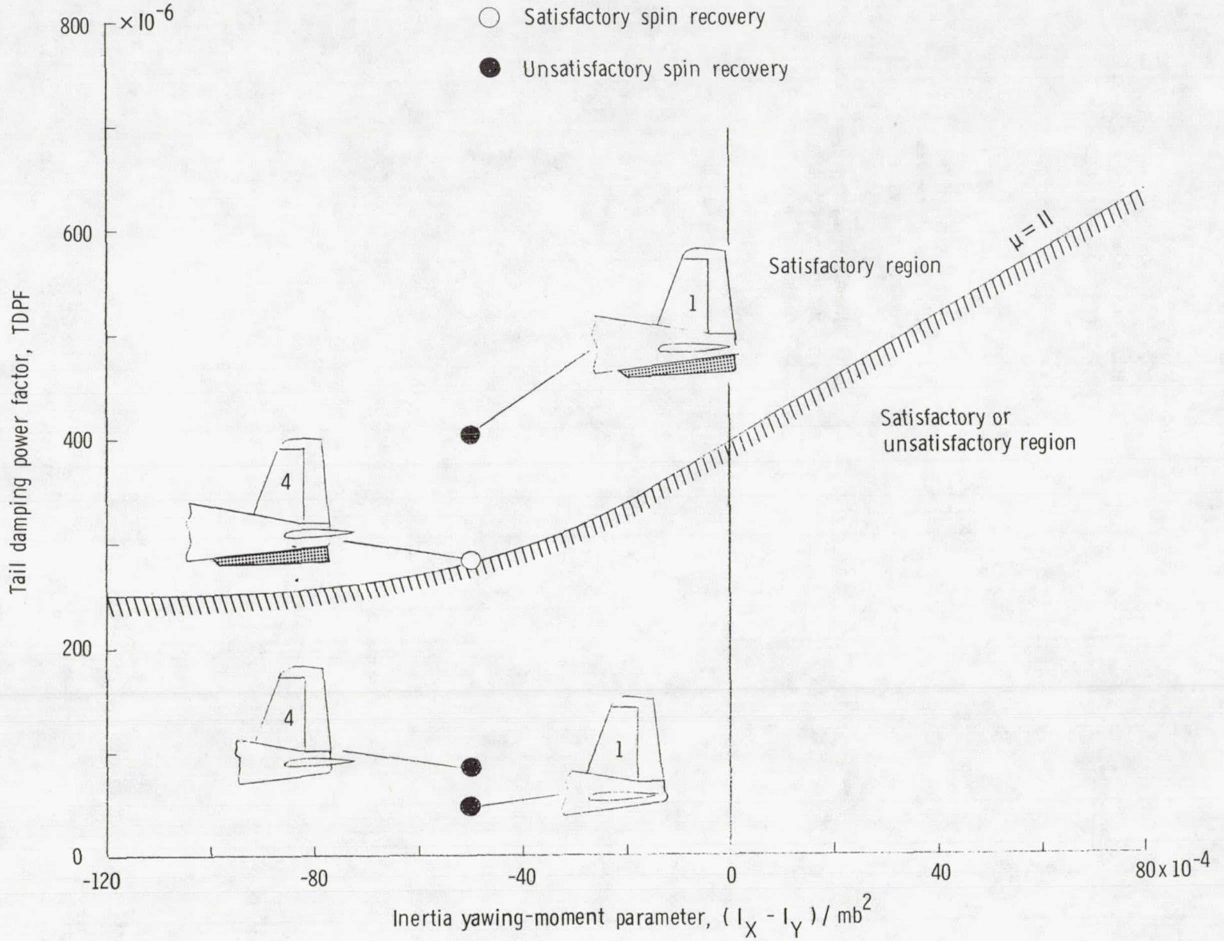


Figure 16.- Effect of ventral fins on spin-recovery characteristics using aileron-deflected data with the tail design criterion. Recovery attempted by rudder alone.

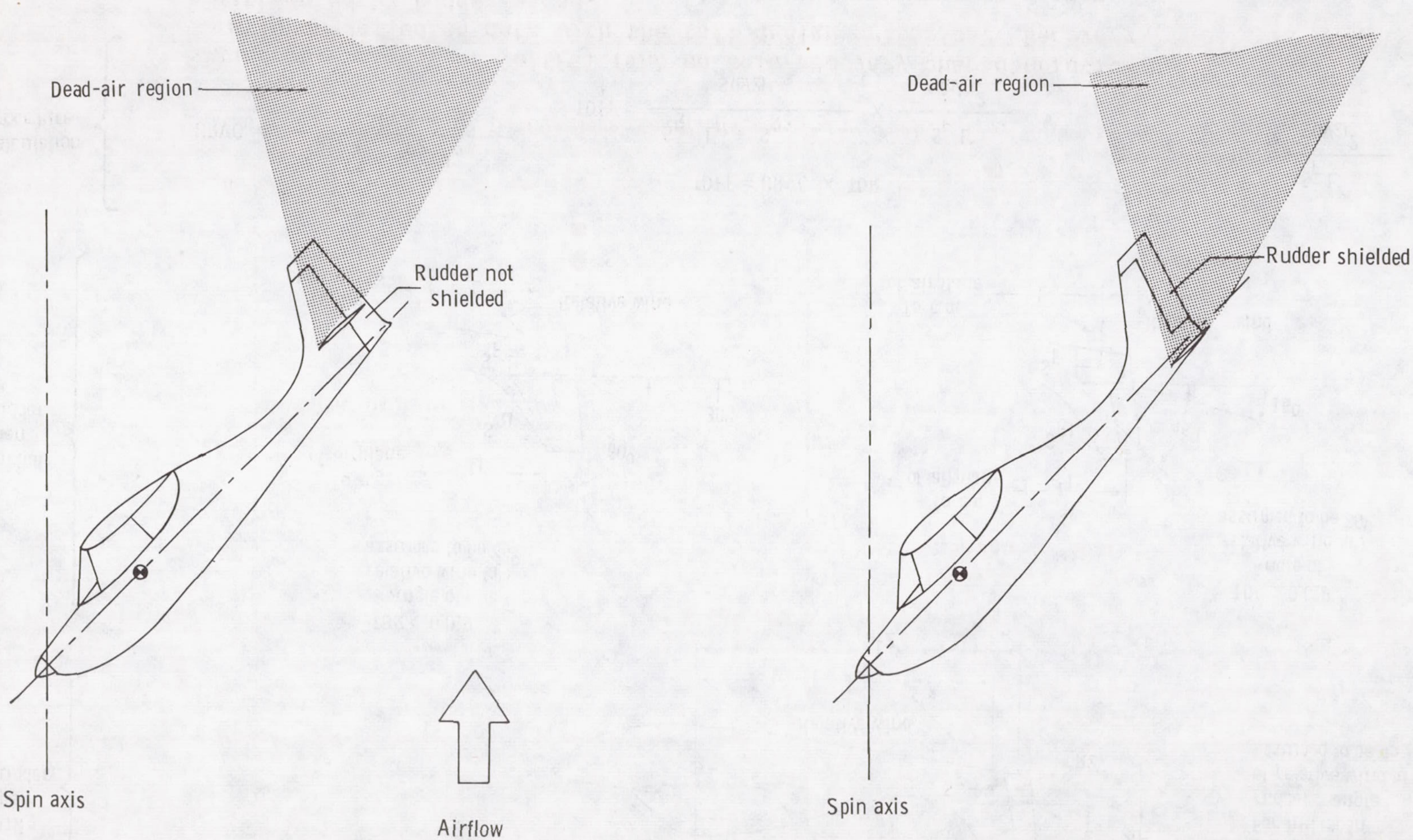
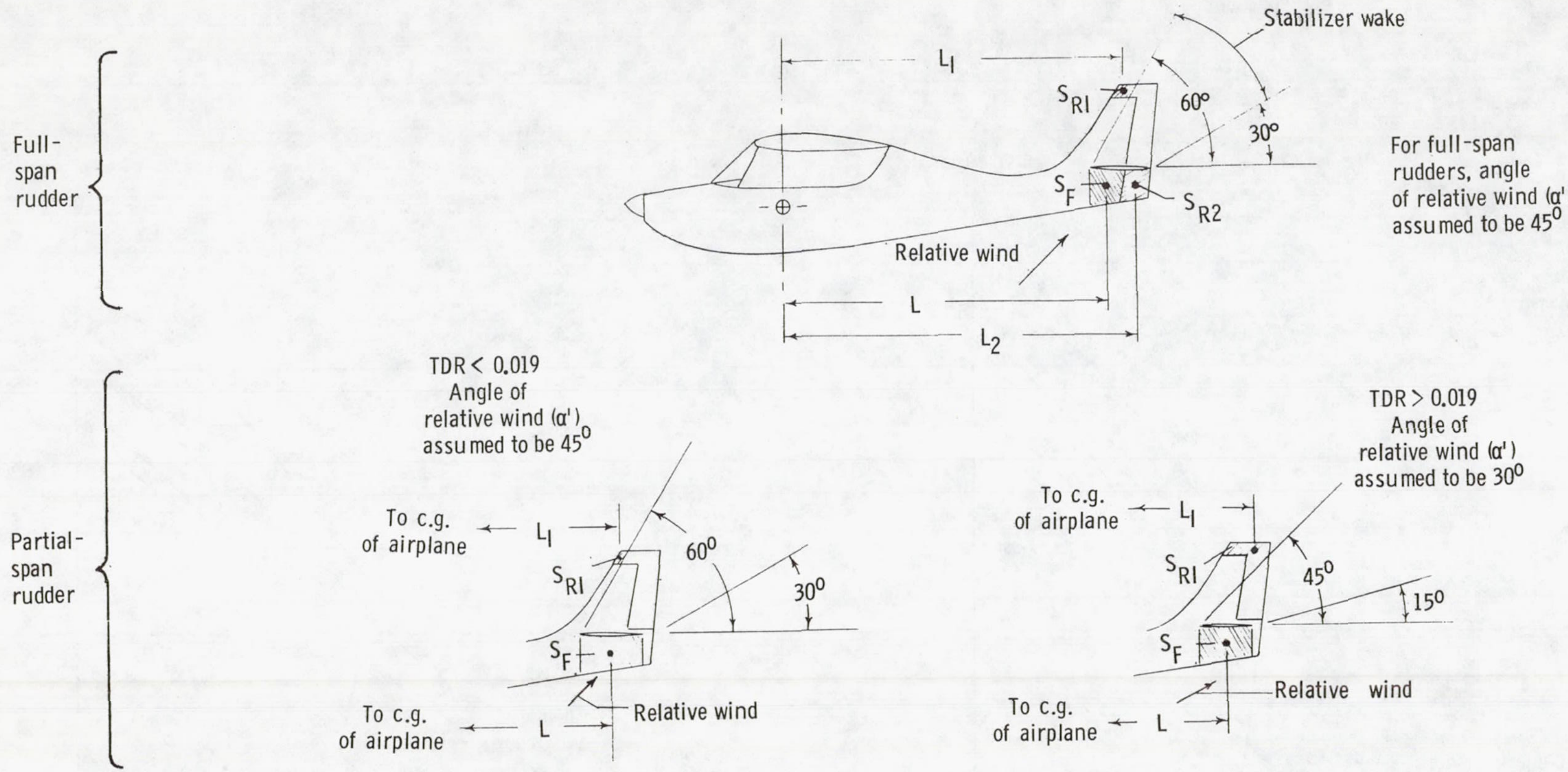


Figure 17.- Effect of horizontal-tail shielding on rudder.



Calculation procedure

$$\text{URVC} = \frac{S_{R1} L_1 + S_{R2} L_2}{S(b/2)}$$

$$\text{TDPF} = \text{URVC} \times \text{TDR}$$

$$\text{TDPF} = \frac{S_{R1} L_1 + S_{R2} L_2}{S(b/2)} \times \frac{S_F L^2}{S(b/2)^2}$$

$$\text{TDR} = \frac{S_F L^2}{S(b/2)^2}$$

Figure 18.- Method of computing tail damping power factor.

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16. Abstract

An investigation has been performed in the Langley spin tunnel on a 1/11-scale model of a research airplane which represents a typical low-wing, single-engine, light general aviation airplane. The investigation was made to determine the effects of tail design on spin and recovery characteristics and to evaluate a tail design criterion for satisfactory spin recovery for light airplanes. The effects of other geometric design features on the spin and recovery characteristics were also determined. The results of the investigation indicated that the existing tail design criterion for light airplanes, which uses the tail damping power factor (TDPF) as a parameter, cannot be used to predict spin-recovery characteristics.

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