Copy No. 1

CONFIDENTIAL

RM No. L8D27

NACA RM No. L8D27

NACA

RESEARCH MEMORANDUM

METHOD OF ESTIMATING THE MINIMUM SIZE OF A TAIL OR WING-TIP PARACHUTE FOR EMERGENCY SPIN RECOVERY OF AN AIRPLANE

By

Frank S. Malvestuto, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
October 27, 1948

CONFIDENTIAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

METHOD OF ESTIMATING THE MINIMUM SIZE OF A TAIL OR WING-TIP PARACHUTE FOR EMERGENCY SPIN RECOVERY OF AN AIRPLANE

By Frank S. Malvestuto, Jr.

SUMMARY

This paper presents a method for estimating the size of a tail or wing-tip parachute required for satisfactory emergency recovery of airplanes during spin demonstrations. The method was developed from an analysis of the results of investigations conducted in the Langley 20-foot free-spinning tunnel with dynamically scaled models of 23 airplanes. A comparison of the parachute sizes calculated by this method with the sizes determined experimentally indicated fairly satisfactory agreement. A method is also included which will enable the approximate estimation of the magnitude of the shock load associated with the rapid opening of the parachute.

INTRODUCTION

The spin-recovery parachute is a temporary emergency device normally used on airplanes during full-scale spin demonstrations in order to terminate uncontrollable spins. Gnerally, the spin-recovery-parachute size is determined from an investigation with a scaled model of the airplane in the Langley 20-foot free-spinning tunnel such as reported in reference 1. The purpose of this paper is to present a method of estimating from design data the minimum size of a flat-type tail or wing-tip spin-recovery parachute necessary for recovery from a spin. Wing-tip parachutes attached only to the outboard wing are considered in this paper inasmuch as reference 1 indicates that wing-tip parachutes so located are effective for spin recovery. The method is based upon a study of the results of free-spinning tests of 23 scaled models of airplanes for which recoveries were attempted by parachute action alone from the normal-control configuration for spinning (ailerons neutral, elevator up, and rudder with the spin).

SYMBOLS

The quantities defining the attitude and rotation of an airplane in a spin are shown in the sketch of figure 1.

b	wing span, feet
S	wing area, square feet
F	effective damping area, square feet (see fig. 2)

L	moment arm of damping area F, feet (see fig. 2)
TDR	tail-damping ratio (see fig. 2)
W	gross weight of airplane, pounds
g	acceleration due to gravity, feet per second^2
m	mass of airplane, slugs $\left(\frac{W}{g}\right)$
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
I_X, I_Y, I_Z	moments of inertia about X-, Y-, and Z-body axes, respectively, slug-feet^2
$\frac{I_X - I_Y}{mb^2}$	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
V	full-scale rate of descent of airplane, feet per second
V_R	resultant velocity at parachute, feet per second (assumed equal to resultant velocity at towline attachment point)
V_Y	component of resultant velocity at tail parachute parallel to Y-body axis, feet per second
V_X	component of resultant velocity at wing-tip parachute parallel to X-body axis, feet per second
ρ	air density, slugs per cubic foot
α	angle between thrust line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle of wing inclination below the horizontal, degrees

σ angle between flight path and vertical axis, degrees

β approximate angle of sideslip at center of gravity; equals $\phi - \sigma$ (sideslip positive and inward for a right spin when inner wing is down by an amount greater than the helix angle)

Ω angular rotation about vertical axis, radians

d_o minimum laid-out-flat parachute diameter, feet

$(S)_p$ surface area of parachute, square feet $\left(\frac{\pi d_o^2}{4}\right)$

$(D)_p$ drag of parachute, pounds

$(C_D)_p$ drag coefficient of parachute $\left(\frac{(D)_p}{\frac{1}{2}\rho V_R^2 (S)_p}\right)$

$(N)_p$ yawing moment of parachute about normal body axis, foot-pounds

$(C_n)_p$ yawing-moment coefficient developed by parachute $\left(\frac{(N)_p}{\frac{1}{2}\rho V^2 Sb}\right)$

D drag of complete airplane, pounds

C_D drag coefficient of complete airplane $\left(\frac{D}{\frac{1}{2}\rho V^2 S}\right)$

l_t distance along the X-body axis between the attachment point of the tail-parachute towline and the center of gravity of airplane, feet

l_y distance along the Y-body axis between the attachment point of the wing-tip-parachute towline and the plane of symmetry, feet $\left(\text{equal to } \frac{b}{2} \text{ for models in this paper}\right)$

δ_r rudder deflection, degrees

δ_e elevator deflection, degrees

δ_a deflection of each aileron, degrees

Subscripts:

T	tail parachute
W	wing-tip parachute

METHOD

Experimental Data

The experimental data used in the analysis have been obtained from the results of tests of free-spinning airplane models in the Langley 20-foot free-spinning tunnel, the design and operation of which is similar to that of the Langley 15-foot free-spinning tunnel described in reference 2. Figure 1 is a sketch of a model (or airplane) in a spin and shows the quantities that are measured in the free-spinning-tunnel tests to determine the attitude (angles α and ϕ) and motion (velocity V and rotation Ω) of the model in a spin. Dynamically scaled models of full-scale airplanes were made to recover from spins by the use of model parachutes attached either to the outer wing tip of the model (fig. 3) or to the tail (fig. 4). For the models considered herein, the towline point of attachment for the tail parachute was located near the rudder hinge line (or hinge line extended for partial-length rudders) midway between the horizontal tail and bottom of fuselage. Three-view drawings and plots of the turns for recovery with different diameter parachutes for each of the 23 models considered in the present investigation are presented in figure 5. Table I contains pertinent mass and dimensional data and table II contains steady-spin data for these models. A photograph of a typical flat-type-model parachute used in the investigation is presented in figure 6 together with a sketch of the parachute canopy when spread out on a flat surface. The shroud lines for these parachutes were made 1.35 times the diameter of the parachute. It had previously been found in tunnel tests (reference 3) that with shroud lines greater than 1.25 times the diameter of the parachute the drag coefficient varied only slightly with change in shroud line length. More details concerning flat-type parachutes are given in reference 1.

The drag coefficients of some of the parachutes used for the spin-recovery tests were determined by free drop tests of these model parachutes in the tunnel. For the remainder of the parachutes the drag coefficients were assumed to be 0.70 which is an average parachute drag coefficient determined from model tests reported in reference 1 and from the results of unpublished tests.

Analysis

Criterion.- The parachute which gives a 2-turn recovery by parachute action alone from the normal-control configuration for spinning or a $2\frac{1}{4}$-turn recovery from the so-called "criterion spin" is normally considered to be the minimum-size parachute. For the criterion spin (reference 4) the controls are set as follows: rudder full with the spin, elevator two-thirds of full-up deflection, and the ailerons deflected one-third of full deflection in the direction (with or against the spin) conducive to slower recoveries. In choosing the experimentally determined parachute diameters that were applied in the present analysis, however, the parachute diameter which gave approximately a $1\frac{1}{2}$-turn recovery instead of a 2- or $2\frac{1}{4}$-turn recovery as suggested by the criterion stated previously was used inasmuch as for some models the minimum parachute diameter for a 2-turn or $2\frac{1}{4}$-turn recovery (criterion spin) as determined from tests was critical because of the rapid increase of turns for recovery with parachute diameter as the diameters approached and became slightly smaller than this minimum-size parachute.

It should be pointed out that the method to be presented has been developed primarily for recoveries by parachute action alone with the controls of the airplane in the normal or "criterion" setting. Generally, however, during full-scale spins, the pilot will attempt recovery by control movement and will use the parachute only if the spin is not terminated by manipulation of the controls. In this case it is likely that, if the pilot needs to use the parachute, the controls of the airplane will not be in the normal or criterion position. The parachute diameter estimated from the method presented herein, however, will still be satisfactory provided the ailerons are approximately neutral and the elevator up. It is possible to attempt to recover from the spin by reversal of rudder and elevator and unintentionally put the airplane into a spin with the elevators down and with possibly a with or against the spin setting of the ailerons. In this case, it is recommended that the pilot move the controls of the airplane to the position normal for spinning before attempting recovery by parachute action inasmuch as experience and the results of unpublished tests indicate that the method may underestimate the size parachute required for recovery from such control configurations.

Assumptions.- In order to simplify the analysis so that a practical estimation could be evolved, the following assumptions were made:

(a) After the parachute was fully bloomed, it was assumed that the parachute and towline remained fixed with respect to the airplane with the towline alined with the relative wind at the point of attachment to the airplane and that the parachute drag force acted along the towline.

(b) The magnitude of the drag force generated by the fully bloomed parachute could be determined by considering the resultant velocity at the point of attachment of the towline instead of at the parachute. This, in effect, assumes a negligible effect of towline length on parachute action in producing recoveries. The experimental data of reference 1 partially verifies this assumption in that it indicates that for tail parachutes for towline lengths greater than 20 feet and less than 50 feet – approximately the range of towline lengths for the models analyzed herein – the effect of the towline length on turns for recovery is negligible. For parachutes attached to the outer wing tip the results of reference 1 indicate no appreciable effect of towline length on parachute effectiveness. For both tail and wing-tip parachutes, however, extremely short towlines may cause the parachute to be in the flow wake from the tail or wing surface and promote improper opening of the parachute.

Development of Equations

The effectiveness of a tail or wing-tip spin-recovery parachute in promoting recoveries from spins by parachute action alone is probably caused to a large extent by the yawing moment acting against the spin generated by the fully opened parachute (reference 1). This importance of yawing moment in stopping the airplane spin has been realized from past investigations on spinning airplanes (references 5 and 6) in which it has been pointed out that upsetting yawing-moment equilibrium would ultimately result in a recovery from the spin, whereas disturbances in the rolling- and pitching-moment equilibrium would be compensated for by changes in sideslip and rate of rotation. Hence, it was felt that, if for any airplane the value of the yawing moment necessary for a satisfactory recovery could be determined, then it would be possible to estimate the minimum size of the tail or wing-tip parachute required for satisfactory recovery. This yawing moment needed for recovery can be calculated by determining the drag force for the parachute giving the satisfactory number of turns for recovery and also the effective yawing-moment arm of this drag force about the Z-body axis of the airplane. On this basis, calculations were prepared to determine the value of the anti-spin yawing moment actually developed by the minimum-size spin-recovery parachute for each of 23 models tested in the Langley 20-foot free-spinning tunnel by considering the relative position of the fully bloomed parachute and airplane and the steady-spinning motion of the model prior to the blooming of the parachutes. This value of the yawing moment of the parachute calculated for each airplane and denoted nondimensionally by $(C_n)_p$ was determined by the following equations which are developed in the appendix.

Tail parachute

$$(C_n)_p = \frac{\pi(d_o)_T^{\,2}}{4}(C_D)_p\left(\frac{l_t}{Sb}\right)\left(\frac{V_Y}{V_R}\right)_T\frac{(V_R)_T^{\,2}}{V^2} \tag{1}$$

Outer wing-tip parachute

$$(C_n)_p = \frac{\pi (d_o)_W^{\ 2}}{4} (C_D)_p \left(\frac{l_y}{Sb}\right) \left(\frac{V_X}{V_R}\right)_W \frac{(V_R)_W^{\ 2}}{V^2} \qquad (2)$$

In formulas (1) and (2) the minimum-diameter tail and wing-tip parachute for each model $(d_o)_T$ and $(d_o)_W$ were obtained from the results of free-spinning tests presented in figure 5. The quantities $\left(\frac{V_Y}{V_R}\right)_T$, $\left(\frac{V_X}{V_R}\right)_W$, $\frac{(V_R)_T^{\ 2}}{V^2}$, and $\frac{(V_R)_W^{\ 2}}{V^2}$ were calculated for each model as accurately as possible using free-spinning test data (α, ϕ, V, and Ω) obtained from observations and film records of each test. It should be pointed out that the quantities $\frac{(V_R)_T^{\ 2}}{V^2}$ and $\frac{(V_R)_W^{\ 2}}{V^2}$ are each sufficiently close to unity that the substitution of unity for these quantities in equations (1) and (2) will not appreciably alter the values of $(C_n)_p$ calculated from these equations. The value of the drag coefficient, as mentioned previously, was determined from tests of the model parachute or a value was assumed based on the results of previous investigations (reference 3). The values of l_t, l_y, S, and b were obtained from design data for the models. The values of $(C_n)_p$ calculated from equations (1) and (2) together with the values of $(d_o)_T$, $(d_o)_W$, $\left(\frac{V_Y}{V_R}\right)_T$, and $\left(\frac{V_X}{V_R}\right)_W$ used to determine $(C_n)_p$ are presented in table II for each model considered herein. The quantities $\frac{(V_R)_T^{\ 2}}{V^2}$ and $\frac{(V_R)_W^{\ 2}}{V^2}$ as indicated previously can be closely approximated by unity and therefore have not been presented in table II.

An examination of equations (1) and (2) shows that, if $(C_n)_p$, $\left(\frac{V_Y}{V_R}\right)_T$, and $\left(\frac{V_X}{V_R}\right)_W$ can be determined for any airplane together with an estimation of $(C_D)_p$ the drag coefficient of the parachute, it is then possible to calculate $(d_o)_T$ or $(d_o)_W$ the minimum-diameter tail or wing-tip spin-recovery parachute.

A study of the spin results and dimensional characteristics of the models presented herein indicated that the value of $(C_n)_p$ determined from equations (1) and (2) depended mainly upon the value of the tail-damping ratio TDR of the model. (See fig. 7.) The magnitude of the quantity TDR is an approximation of the effectiveness of the airplane to damp its rotation in a spin, the fuselage area under the horizontal tail being considered the "effective damping area." This factor is discussed in reference 4 and the method of calculating its value is shown in figure 2. Values of $(C_n)_p$ approaching 0.05 as the value of TDR becomes small are not unreasonable when it is realized that the parachute is acting against the combined pro-spin yawing power of the wing and of the rudder set with the spin of the airplane. For large values of TDR, however, the value of $(C_n)_p$ required is relatively less since the parachute is now effectively assisted by the damping moment of the TDR area in producing recoveries. The scatter of test points in figure 7 has been associated with a number of causes. First, the test data were incomplete and it was not always possible to choose reliably a parachute diameter which gave a $1\frac{1}{2}$-turn recovery – the recovery criterion used to choose the parachute diameters for the determination of $(C_n)_p$. For model 15, for example, the tail-parachute diameter which gave a $\frac{1}{2}$-turn recovery was used in estimating $(C_n)_p$ because data were not available for recoveries near $1\frac{1}{2}$ turns. Another possible cause for the scatter of points on figure 7 is that for some airplanes the TDR as calculated may not be an accurate indication of the effectiveness of these airplanes in damping the rotation in spins.

For the estimation of the factors $\left(\frac{V_Y}{V_R}\right)_T$ and $\left(\frac{V_X}{V_R}\right)_W$, an average was taken of the accurately determined values of each of these factors for the 19 conventional airplanes listed in table II and 10 additional models not listed in this paper. From this average, for use in equations (1) and (2) we may set $\left(\frac{V_Y}{V_R}\right)_T = 0.22$ and $\left(\frac{V_X}{V_R}\right)_W = 0.80$. A study of the spin characteristics of a large number of models indicated that these "averaged" values of $\left(\frac{V_Y}{V_R}\right)_T$ and $\left(\frac{V_X}{V_R}\right)_W$ are just as accurate as values that may be calculated from empirical formulas developed from rough relationships between the spin characteristics and mass and dimensional characteristics of an airplane.

RESULTS AND DISCUSSION

Conventional Airplane

A comparison of the minimum-diameter tail and wing-tip parachutes as determined from the free-spinning-model tests and those calculated by solving equations (1) and (2) for $(d_o)_T$ and $(d_o)_W$ and using the values of $(C_n)_p$ from figure 5 and letting $\left(\frac{V_Y}{V_R}\right)_T = 0.22$ and $\left(\frac{V_X}{V_R}\right)_W = 0.80$ are presented in figures 8(a) and 8(b). In general, the correlations between the experimental and calculated minimum-size diameters are reasonably satisfactory. It therefore appears that in using the experimental parachute diameter as a basis the method of estimating spin-recovery parachute diameters presented herein is accurate to ±1 foot although in some cases the accuracy of the method was less. An indication of the accuracy of applicability of the method to full-scale airplanes may be obtained from table III which presents for each of five conventional-type airplanes a comparison between the spin-recovery-parachute diameter that caused a satisfactory recovery from the full-scale spin and the minimum-diameter parachute for the same airplane estimated using the method given herein. This comparison shows a satisfactory agreement between the full-scale results and the estimations; particularly, if it is pointed out that for the full-scale tests the control positions were not in the normal or "criterion" configurations, a stipulation, as mentioned previously, in the development of the method.

For this analysis, as stated previously, it was assumed that for any one airplane a specific amount of anti-spin yawing moment is required for its recovery from the steady-spin condition. Hence, the parachute whether it is attached to the tail or wing tip would need to supply this specific amount of anti-spin yawing moment for recovery. A study of table II indicated that, in general, the anti-spin yawing-moment coefficients for the tail and wing-tip parachutes which gave satisfactory recoveries were approximately the same for any one airplane. This fact lends support to the assumption that at least for the range of mass distribution of the models considered herein (see table I) the yawing moment of the parachute is important for recovery inasmuch as the over-all action on the spin of the tail parachute and of the wing-tip parachute is quite different. It can be seen, based on this line of reasoning, that for any one airplane for a satisfactory recovery from the spin the diameter wing-tip parachute required will be smaller than the diameter tail parachute required in the ratio $\sqrt{\frac{1}{l_y}\left(\frac{V_R}{V_x}\right)_W} \Big/ \sqrt{\frac{1}{l_t}\left(\frac{V_R}{V_y}\right)_T}$. If we assume that l_t is equal to l_y (= b/2) which is approximately true for most of the airplanes considered herein and also let $\left(\frac{V_X}{V_R}\right)_W = 0.80$ and $\left(\frac{V_Y}{V_R}\right)_T = 0.22$, as indicated previously, then the ratio

$\sqrt{\left(\frac{V_R}{V_X}\right)_W} \Big/ \sqrt{\left(\frac{V_R}{V_Y}\right)_T} = \sqrt{\frac{0.22}{0.80}} \approx 0.53$ is the ratio of the minimum-size wing-tip-parachute diameter to the minimum-size tail-parachute diameter based upon the assumptions and on the formulas derived herein. The results of the parachute tests presented in figure 5 indicate that, in general, the minimum-size wing-tip parachute is approximately one-half of the minimum-size tail parachute which is in agreement with the calculated ratio.

The applicability of the method presented herein to airplanes whose mass loadings do not fall within the range of mass loadings of the airplanes considered in the analysis may yield inaccurate estimations of the minimum-size spin-recovery parachutes for these airplanes. Although there is little experimental data to verify this statement, it may be explained on the basis of an assumed similarity between the effect of control manipulation and parachute action on the spin of an airplane. Reference 7 indicates that, for airplanes heavily loaded along the wings, setting ailerons against the spin and reversing the elevator from up to down will cause a rapid recovery; whereas if the airplane is heavily loaded along the fuselage, setting ailerons with the spin and reversing the rudder from with to against the spin will be the optimum control manipulation. The parachute attached to the outer wing tip will in its action after fully bloomed cause a pro-spin rolling moment and an anti-spin yawing moment to act about the body axes of the airplane. It simulates the situation in which the ailerons are set with the spin and the rudder is reversed for effective recovery. The wing-tip parachute, therefore, should be highly effective when the airplane is heavily loaded along the fuselage and should lose its effectiveness (increase of diameter) when the airplane is heavily loaded along the wings, because for this latter loading an anti-spin rolling moment (ailerons against the spin) and a nose-down pitching moment (downward movement of elevator) conducive for a fast recovery can be obtained more fully by the use of a tail parachute than a parachute attached to the outer wing tip. Additional research is needed before any quantitative evaluation of the effect of mass distribution on the minimum-size spin-recovery parachute can be determined.

The parachutes considered in this paper are of the conventional flat-type design which have been found to be inherently unstable for the range of porosities of the fabrics generally used in the manufacture of this type of parachute. Recently tests have been conducted in the Langley 20-foot free-spinning tunnel with five airplane models to determine the spin-recovery effectiveness of high-porosity stable parachutes that are hemispherical in shape when fully bloomed. The results of these tests and a comparison of these results with the results of corresponding tests using the same models but with the flat-type parachute as a spin-recovery device are presented in reference 8. It is indicated in the reference paper that, in general, the hemispherical-type parachute gave spin recoveries equally as good as flat-type parachutes when the projected diameter of the hemispherical parachute was about two-thirds the laid-out-flat diameter of the flat-type parachute.

On this basis if a hemispherical-type parachute is used as a spin-recovery device, the minimum projected diameter of the hemispherical parachute required will be equal to two-thirds the minimum diameter of the flat-type parachute obtained by the method presented herein.

Tailless Aircraft

The formulas given previously for estimation of the minimum-size spin-recovery parachute for the conventional-type airplane cannot be directly applied to tailless designs inasmuch as the present method of calculating TDR does not apply to this type of airplane. For tailless designs a value of $(C_n)_p = 0.02$ is considered satisfactory from a study of the data and discussions of references 5 and 6 and unpublished results of a similar nature. The equation for estimation of the minimum parachute diameter for tailless aircraft is then

$$(d_o)_W = \frac{2}{\sqrt{\pi}} \sqrt{\frac{0.02}{(C_D)_p} \left(\frac{Sb}{l_y}\right) \left(\frac{V_R}{V_X}\right)_W} \tag{3}$$

The moment arm l_y is used in this equation since it is assumed that the point of attachment of the parachute is on the lateral axis of the airplane that extends through the center of gravity. An analysis of free-spinning-test results for four tailless-aircraft models indicates that an average value of 1.2 gave a satisfactory representation of the quantity $\left(\frac{V_R}{V_X}\right)_W$. Making this substitution, equation (3) becomes

$$(d_o)_W = 0.17 \sqrt{\frac{1}{(C_D)_p} \left(\frac{Sb}{l_y}\right)} \tag{4}$$

If l_y is assumed equal to $\left(\frac{b}{2}\right)$, equation (4) becomes

$$(d_o)_W = 0.24 \sqrt{\frac{S}{(C_D)_p}} \tag{5}$$

Table IV presents a comparison of calculated diameters using equation (5) and experimentally determined diameters for two tailless models tested in the Langley 20-foot free-spinning tunnel. Although the data are meager, the correlation for the models presented is considered satisfactory.

Estimation of Shock Load Developed by the

Opening of the Spin-Recovery Parachute

The shock load can be defined as the steady-state load acting on the parachute times a shock-load factor. The steady-state load is merely the load that would be acting on the parachute after it is fully opened in an air stream having a velocity which is equal to the resultant velocity at the parachute when it is attached to the spinning airplane. The shock-load factor is a coefficient which gives the ratio of the maximum load developed by the parachute during its rapid opening process (shock load) to the steady-state load. Reference 3 indicates from a series of wind-tunnel tests with full-scale spin-recovery parachutes that the shock-load factor may be as large as 2.3. The shock load can then be determined from the equation

$$\text{Shock load} = 2.3\,(C_D)_p\left(\frac{1}{2}\rho V_R{}^2\right)(S)_p \qquad (6)$$

In the dynamic-pressure term of equation (3) the velocity V_R may be assumed to be closely approximated by V, the rate of descent of the airplane. From a study of the geometry of the spin for zero sideslip at the center of gravity it can be shown that $V = \sqrt{\frac{2W}{C_D \rho S}}$. In this relationship the value of C_D – the drag coefficient of the airplane – can be assumed approximately equal to 0.6 when the TDR of the airplane is greater than 0.02 and C_D equal to 1.0 when the TDR value is less than 0.02. These values have been derived from a study of the results of tests of over 50 free-spinning-model airplanes. With proper substitution equation (6) now becomes

$$\text{Shock load} = 2.3\left\{(W)\left[\frac{(C_D)_p}{C_D}\right]\left[\frac{(S)_p}{S}\right]\right\} \qquad (7)$$

where C_D is to be determined by the method previously given.

CONCLUDING REMARKS

1. A method has been developed for the estimation of the diameter of the tail or wing-tip spin-recovery parachute required for a 2-turn recovery from the normal-control spin by parachute action alone. A correlation of the calculated parachute diameters with the parachute diameters determined from free-spinning-model tests and from full-scale spin tests of five conventional-type airplanes indicates that the method developed herein will enable fairly satisfactory estimations

to be made of the minimum-diameter tail or wing-tip spin-recovery parachute for airplanes which fall within the limits of the mass and dimensional parameter range considered.

2. A method is also presented which will enable the approximate estimation of the magnitude of the shock load associated with the rapid opening of the parachute.

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

APPENDIX

DEVELOPMENT OF EQUATIONS (1) AND (2)

Equations (1) and (2) enable the computations of the yawing-moment coefficient developed by the tail or wing-tip parachute in effecting the recovery from the spin of a free-spinning model. The equations are developed as follows:

Tail parachutes.- In accordance with the assumptions presented in the text, the drag of the parachute co-linear with the towline direction is equal to

$$(D)_p = (C_D)_p\left[\frac{1}{2}\rho(V_R)_T^{\,2}\right](S)_p$$

$$= (C_D)_p\left[\frac{1}{2}\rho(V_R)_T^{\,2}\right]\frac{\pi(d_o)_T^{\,2}}{4} \tag{A1}$$

The component of this drag force $(D)_p$ in the direction of the Y-body axis is

$$(D)_{p_Y} = (D)_p\left(\frac{V_Y}{V_R}\right)_T$$

$$= (C_D)_p\left[\frac{1}{2}\rho(V_R)_T^{\,2}\right]\frac{\pi(d_o)_T^{\,2}}{4}\left(\frac{V_Y}{V_R}\right)_T \tag{A2}$$

where $\left(\frac{V_Y}{V_R}\right)_T$ is the cosine of the angle between the resultant velocity $(V_R)_T$ and the component of resultant velocity along the Y-body axis $(V_Y)_T$. The yawing moment due to the parachute about the Z-body axis of the airplane is then

$$(N)_p = (D)_{p_Y}\, l_t \tag{A3}$$

where l_t is the distance along the X-body axis from the point of attachment of the parachute towline to the center of gravity of the model. Substituting equation (A2) in equation (A3) we obtain

$$(N)_p = (C_D)_p\left[\frac{1}{2}\rho(V_R)_T^{\ 2}\right]\left[\frac{\pi(d_o)_T^{\ 2}}{4}\right]\left(\frac{V_Y}{V_R}\right)_T(l_t) \tag{A4}$$

and nondimensionally $(N)_p$ has the form

$$(C_n)_p = \frac{(N)_p}{\frac{1}{2}\rho V^2 Sb} = \frac{\pi(d_o)_T^{\ 2}}{4}(C_D)_p\left(\frac{l_t}{Sb}\right)\left(\frac{V_Y}{V_R}\right)_T\frac{(V_R)_T^{\ 2}}{V^2} \tag{A5}$$

which is the form of equation (1).

Wing-tip parachutes.- The determination of equation (2) which gives the nondimensional yawing-moment coefficient developed by the parachute attached to the outer wing tip is similar in form to the determination of the equation for tail parachutes; that is, the yawing moment due to the wing-tip parachute about the Z-body axis is given by

$$(N)_p = (C_D)_p\left[\frac{1}{2}\rho(V_R)_W^{\ 2}\right]\left[\frac{\pi(d_o)_W^{\ 2}}{4}\right]\left(\frac{V_X}{V_R}\right)_W(l_y) \tag{A6}$$

where $\left(\frac{V_X}{V_R}\right)_W$ is the cosine of the angle between the resultant velocity at the wing tip $(V_R)_W$ and the component of this resultant velocity along the X-body axis $(V_X)_W$ and (l_y) is the distance along the wing lateral axis between the plane of symmetry and point of attachment of parachute towline. Nondimensionally N is given by

$$(C_n)_p = \frac{(N)_p}{\frac{1}{2}\rho V^2 Sb} = \frac{\pi(d_o)_W^{\ 2}}{4}(C_D)_p\left(\frac{l_y}{Sb}\right)\left(\frac{V_X}{V_R}\right)_W\frac{(V_R)_W^{\ 2}}{V^2} \tag{A7}$$

which is the form of equation (2).

REFERENCES

1. Kamm, Robert W., and Malvestuto, Frank S., Jr.: Comparison of Tail and Wing-Tip Spin-Recovery Parachutes as Determined by Tests in the Langley 20-Foot Free-Spinning Tunnel. NACA ARR No. L5G19a, 1946.

2. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. NACA Rep. No. 557, 1936.

3. Wood, John H.: Determination of Towline Tension and Stability of Spin-Recovery Parachutes. NACA ARR No. L6A15, 1946.

4. Neihouse, Anshal I., Lichtenstein, Jacob H., and Pepoon, Philip W.: Tail-Design Requirements for Satisfactory Spin Recovery. NACA TN No. 1045, 1946.

5. Bamber, M. J., and Zimmerman, C. H.: Effect of Stabilizer Location upon Pitching and Yawing Moments in Spins as Shown by Tests with the Spinning Balance. NACA TN No. 474, 1933.

6. Bamber, M. J., and House, R. O.: Spinning Characteristics of Wings. III - A Rectangular and a Tapered Clark Y Monoplane Wing with Rounded Tips. NACA TN No. 612, 1937.

7. Neihouse, A. I.: A Mass-Distribution Criterion for Predicting the Effect of Control Manipulation on the Recovery from a Spin. NACA ARR, Aug. 1942.

8. Scher, Stanley H., and Draper, John W.: The Effects of Stability of Spin-Recovery Tail Parachutes on the Behavior of Airplanes in Gliding Flight and in Spins. NACA RM No. L8E19, 1948.

CONFIDENTIAL

TABLE II.- CALCULATION OF PARACHUTE YAWING-MOMENT COEFFICIENT FOR 21 FREE-SPINNING MODELS FROM THE RESULTS OF TESTS OF THESE MODELS IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL

Model	Control setting			Steady-spin characteristics				Parachute attached to the tail					Parachute attached to the outer wing tip				
	δ_a (deg) (a)	δ_e (deg) (a)	δ_r (deg) (a)	α (deg)	ϕ (deg)	V (ft/sec)	Ω (radian/sec)	$(d_o)_T$ (ft)	$(C_D)_p$	$\frac{l_t}{Sb}$ (1/(sq ft))	$\left(\frac{V_Y}{V_R}\right)_T$ calculated from tests	$(C_n)_p$	$(d_o)_W$ (ft)	$(C_D)_p$	$\frac{l_Y}{Sb}$ (1/(sq ft))	$\left(\frac{V_X}{V_R}\right)_W$ calculated from tests	$(C_n)_p$
1	N	25U	35W	41	3D	147	2.4	7.0	0.73	0.0016	0.22	0.0098	4.0	0.73	0.0021	0.90	0.0173
2	N	30U	30W	41	2D	226	2.7	11.5	.73	.0018	.20	.0272	5.0	.73	.0017	.88	.0214
3	N	30U	35W	36	4U	178	3.6	8.0	.73	.0018	.34	.0224	5.0	.73	.0020	.99	.0284
4	N	30U	30W	36	2D	239	2.3	9.0	.73	.0017	.15	.0119	7.0	.73	.0018	No data	
5	N	35U	30W	42	1D	203	3.6	8.5	.73	.0024	.23	.0229	5.0	.73	.0023	.90	.0297
6	N	30U	31W	55	1U	197	2.7	11.5	.73	.0020	.25	.0379	5.0	.73	.0021	.76	.0229
7	N	25U	25W	47	2U	243	2.2	12.0	.68	.0010	.27	.0207	8.0	.68	.0010	.84	.0287
8	N	29U	30W	58	0	241	2.3	16.0	.70	.0010	.22	.0309	8.3	.70	.0010	.72	.0273
9	N	23U	31W	44	3D	224	2.6	8.0	.68	.0021	.15	.0108	3.6	.68	.0020	.83	.0115
10	N	25U	30W	41	0	279	2.4	11.0	.70	.0013	.18	.0156					
11	N	35U	25W	56	1U	195	2.2	12.0	.70	.0010	.28	.0221	6.5	.70	.0021	.77	.0375
12	N	30U	28W	48	1U	245	2.9	11.0	.70	.0017	.25	.0283					
13	N	27U	25W	45	2D	279	3.1	10.0	.70	.0022	.11	.0132	4.0	.70	.0019	.80	.0134
14	N	30U	25W	45 37	2U 3D	Approx. 320	2.1	8.0	.67	.0017	.35	.0200	4.0	.74	.0020	.83	.0154
15	5U 5D	23U	25W	52	1D	216	2.4	15.0	.70	.0011	.23	.0313					
16	7U 7D	$27\frac{1}{2}$U	25W	54	0	213	2.6	12.0	.70	.0013	.27	.0278	8.0	.70	.0012	.82	.0346
17	7U 7D	$18\frac{2}{3}$U	30W	47 50	18U 6D	202	2.1	11.7	.70	.0017	.20	.0256	5.8	.70	.0018	.78	.0260
18	4.8U 4.7U	29U	25W	20 35	9U 10D	308	2.5	19.5	.60	.0006	.20	.0215	8.0	.50	.0008	.87	.0175
[b]19	17U	25U	20W	No data				16	.68	.0025	----	------	5.0	.68	.0034	----	------
[c]20	N	30U	30W	No data				15.0	.70	.0007	----	------	8.0	.70	.0009	----	------
21	N	$27\frac{1}{2}$U	30W	63	0	193	3.1						5.0	.70	.0018	.75	.0185

[a]For the "δ_a" column, U and D indicate that the aileron is deflected up or down. For the "δ_e" column U indicates that the elevator is deflected up. For the "ϕ" column U indicates the inner wing in a spin is up or D indicates that the inner wing is down with respect to the horizontal. For the "δ_r" column W indicates rudder is with the spin.

[b]Steady-spin data not obtainable, spin extremely oscillatory.

[c]Steady-spin data not obtainable, model had a high rate of descent.

NACA

CONFIDENTIAL

CONFIDENTIAL

TABLE I.- FULL-SCALE CHARACTERISTICS OF MODELS TESTED

Model	Test altitude (ft)	Gross weight (lb)	Center of gravity $x/\bar{c}$	Span (ft)	Wing area (sq ft)	Moments of inertia			Mass parameters			TDR	l_t (ft)
						I_X (slug-ft^2)	I_Y (slug-ft^2)	I_Z (slug-ft^2)	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$		
1	10,000	4,227	0.291	42.0	239.0	2,659	4,122	6,201	-63×10^{-4}	-90×10^{-4}	153×10^{-4}	0.0140	16.45
2	10,000	11,860	.278	40.8	300.0	13,867	13,047	25,841	14	-210	196	.0164	22.50
3	10,000	4,467	.262	41.0	246.2	2,741	4,237	5,681	-64	-62	126	.0218	17.92
4	10,000	9,277	.268	41.4	275.4	8,920	9,181	17,224	-6	-163	169	.0195	19.11
5	6,000	7,406	.313	34.0	213.0	5,201	6,077	10,704	-33	-174	207	.0234	17.03
6	12,000	8,011	.286	37.3	236.0	4,903	7,237	11,441	-67	-121	188	.0226	18.00
7	20,000	17,036	.274	54.0	493.0	25,977	31,949	56,523	-39	-159	198	.0296	27.65
8	15,000	20,831	.268	50.0	496.0	23,822	31,619	54,321	-48	-140	188	.0147	23.90
9	15,000	8,860	.238	35.5	244.0	5,149	8,176	12,642	-87	-129	216	.0373	18.05
10	15,000	18,648	.240	48.7	380.0	23,195	23,429	42,327	-2	-146	148	.0456	23.60
11	15,000	14,961	.312	49.7	422.0	15,504	21,903	36,240	-56	-125	181	.0208	21.00
12	15,000	16,396	.300	42.5	322.2	16,335	18,011	33,519	-18	-168	186	.0190	22.73
13	15,000	12,963	.270	36.4	260.0	11,714	14,934	25,731	-60	-202	262	.0518	20.58
14	15,000	11,952	.221	38.1	255.3	6,556	13,896	17,962	-121	-90	211	.0378	16.60
15	15,000	18,214	.270	50.0	406.0	16,968	26,404	40,957	-71	-104	175	.0243	23.32
16	15,000	16,378	.255	48.0	400.2	11,516	33,539	42,211	-188	-74	262	.0209	24.43
17	20,000	7,893	.204	42.0	276.2	4,136	9,397	13,461	-122	-94	216	.0260	19.32
18	20,000	26,343	.25	70.2	609	50,666	53,360	97,923	-7	-111	118	.0135	26.00
19	15,000	9,130	.315	32.83	203.5	4,040	11,976	14,904	-260	-96	355	.0480	16.51
20	25,000	19,280	.245	60	548.7	22,645	39,842	58,957	-80	-88	168	.0230	24.57
21	15,000	9,355	.267	40.0	275.0	5,582	11,899	16,532	-134	-102	236	.0285	18.25
22	15,000	9,000	.268	39	293.31	19,151	1,925	20,902	270	-297	27	------	-----
23	15,000	6,526	.290	60	490	19,138	2,274	21,298	231	-260	29	------	-----

CONFIDENTIAL

NACA

TABLE III.- A COMPARISON FOR EACH OF FIVE CONVENTIONAL-TYPE AIRPLANES OF THE TAIL PARACHUTE DIAMETER USED TO OBTAIN A SATISFACTORY RECOVERY FROM THE FULL-SCALE SPIN WITH THE MINIMUM TAIL PARACHUTE DIAMETER ESTIMATED FROM THE METHOD PRESENTED HEREIN

Airplane	Parachute diameter in feet used to obtain a satisfactory recovery from full-scale spin	Minimum parachute diameter in feet estimated from method presented herein
A	6	7.5
B	8	10.0
C	6 (too small)	7
D	8	8
E	7	7

CONFIDENTIAL

TABLE IV.– COMPARISON OF EXPERIMENTALLY DETERMINED AND CALCULATED

FULL-SCALE SPIN-RECOVERY WING-TIP-PARACHUTE DIAMETERS FOR TWO

TAILLESS-AIRCRAFT MODELS

Model	Control settings	Steady-spin characteristics				Parachute diameter (ft)	
		α (deg)	ϕ (deg)	V (ft/sec)	Ω (radian/sec)	From free-spinning tests	Calculated from equation (5)
22	Both elevons deflected up 21° and both elevon balances deflected down 42°. Rudder vertical spread in inches 11.5 up, 11.5 down.	75	0	246	6.02	6.5	5.0
23	Right elevon up 36°. Left elevon down and up 9°. Right scoop rudder deflected 69° down and right pitch flap deflects 26° up.	[a]37 44	[a]4D 3U	158	1.3	5.0	6.5

[a]Oscillatory spin.

CONFIDENTIAL

NACA

CONFIDENTIAL

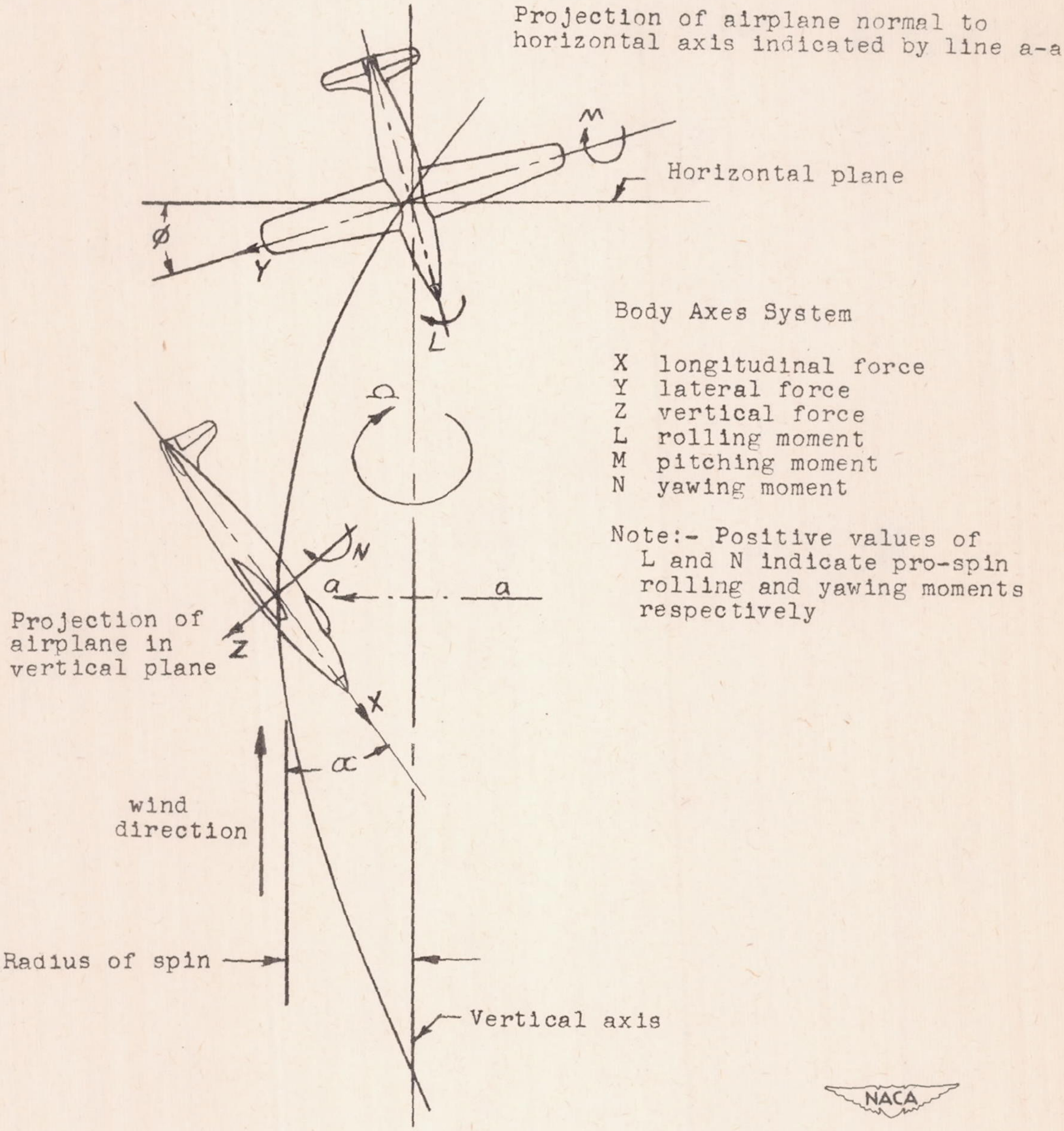
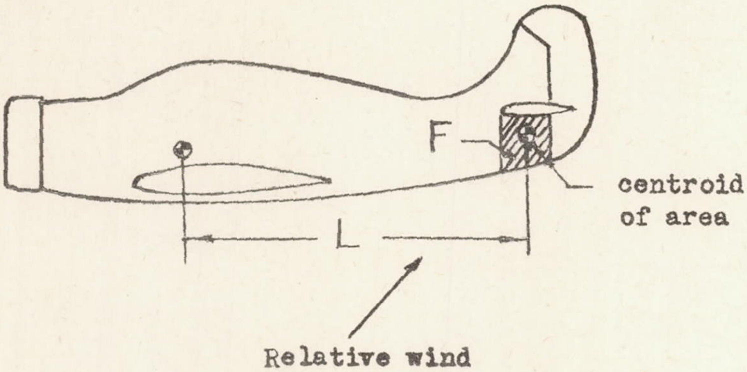


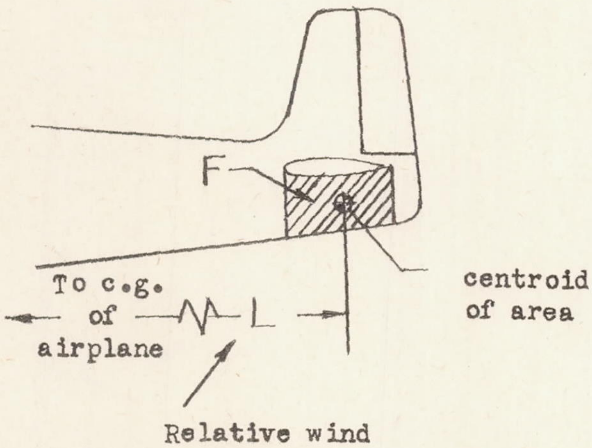
Figure 1.- Sketch of an airplane in a steady spin. Arrows indicate positive direction of forces and moments along and about the body axes of the airplane.

CONFIDENTIAL

CONFIDENTIAL



(a) Full length rudder.



(b) Partial length rudder.

$$\text{Tail-Damping Ratio} = \text{TDR} = \frac{FL^2}{S(b/2)^2}$$

Figure 2.- Method of computing tail-damping ratio, TDR.

CONFIDENTIAL

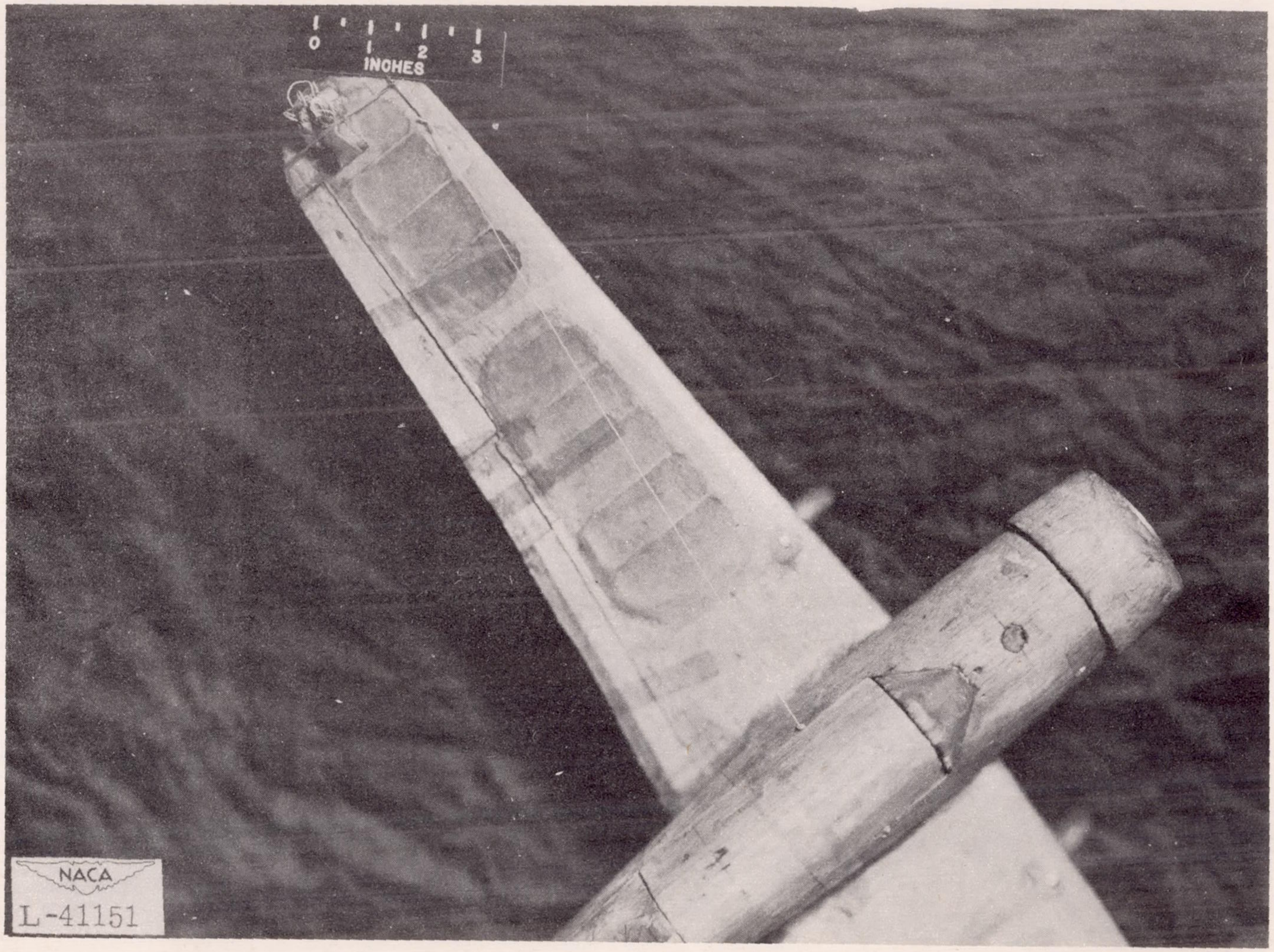


Figure 3.- Typical wing-tip-parachute installation.

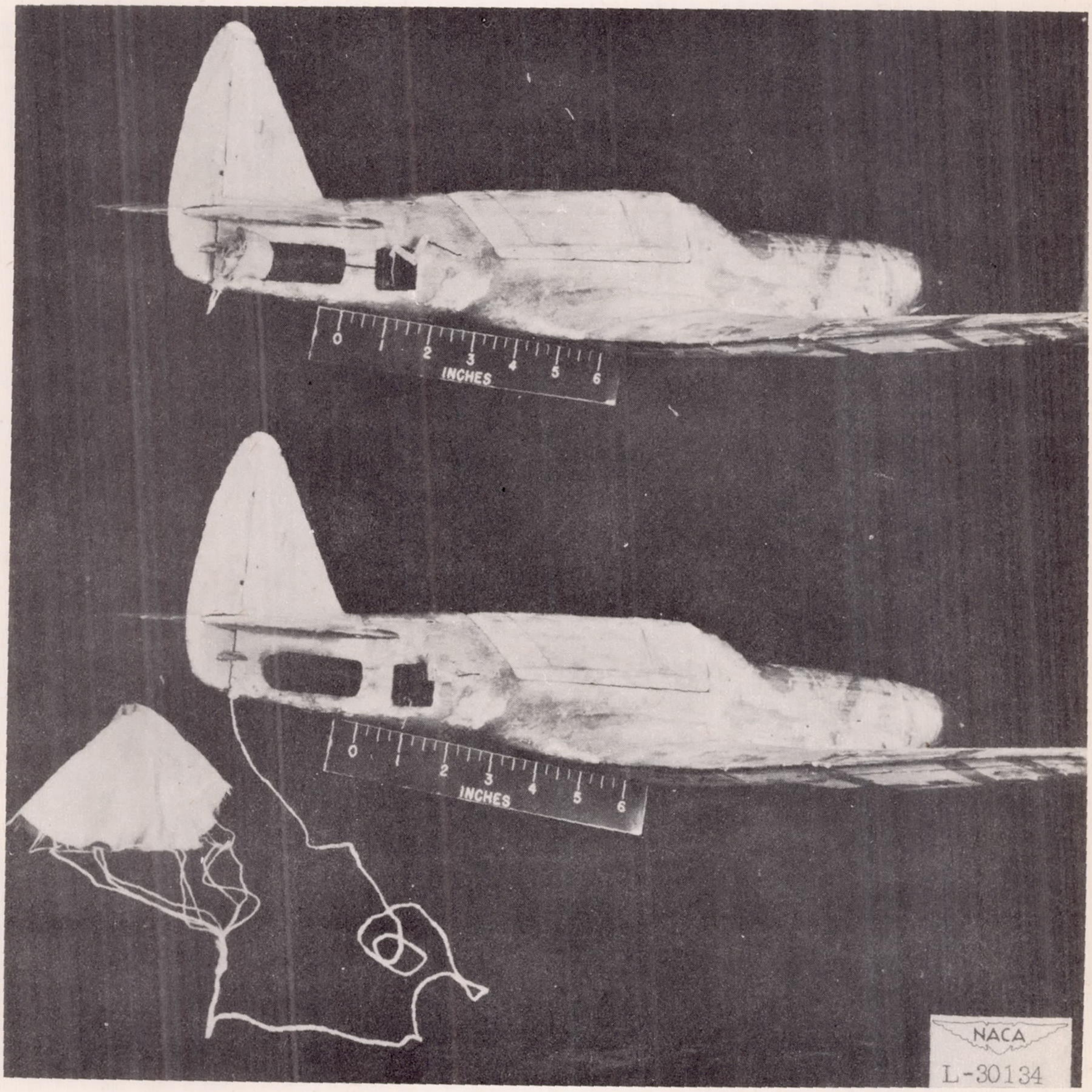


Figure 4.- Parachute-pack installation used in model tests.

CONFIDENTIAL

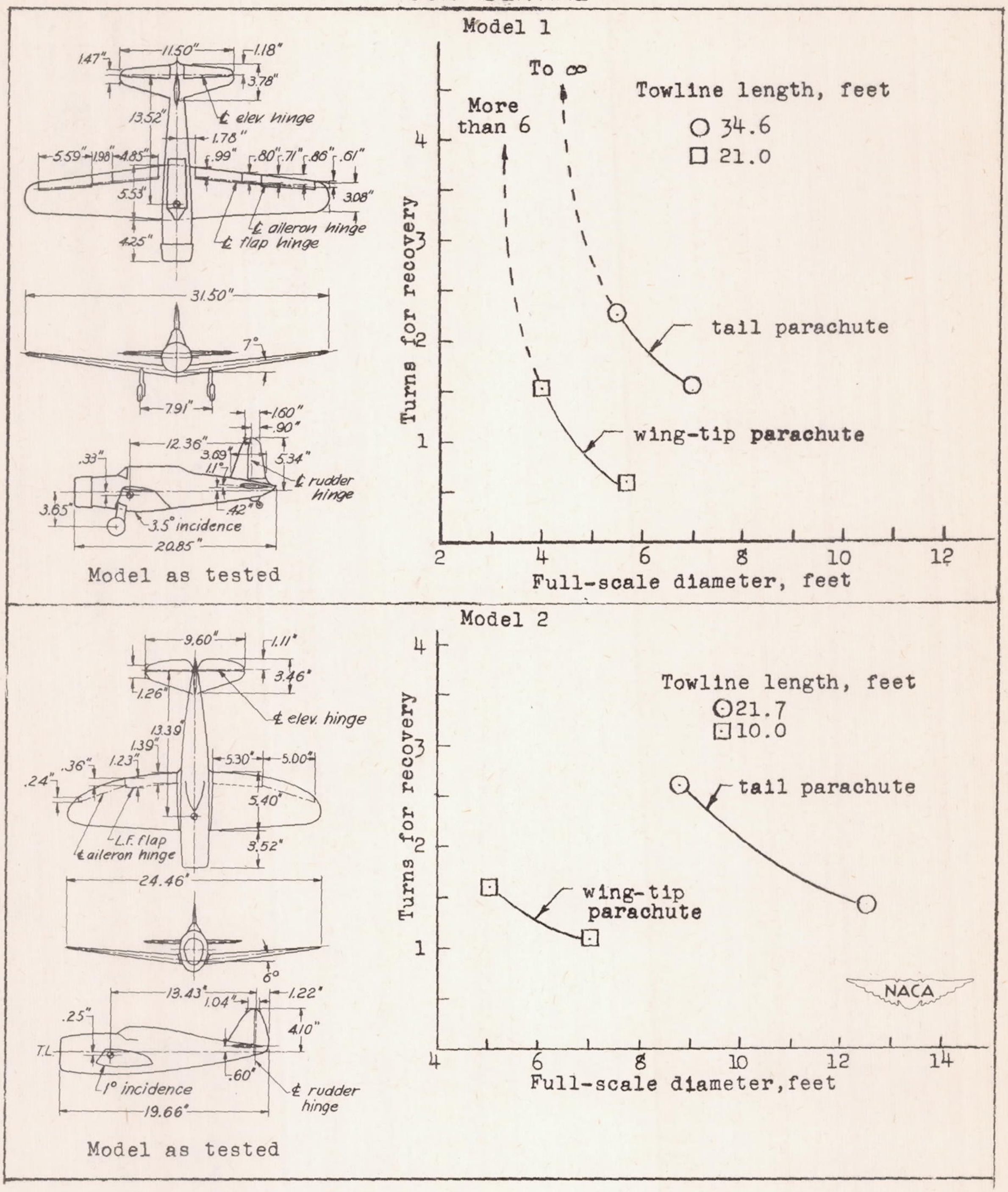


Figure 5.- Three-view drawings of models considered in investigation together with the results of free-spinning model parachute tests giving the variation of parachute diameter with turns for recovery by parachute action alone for each model. Controls kept with the spin (ailerons neutral, elevator full up, rudder full with the spin) unless otherwise indicated.

CONFIDENTIAL

CONFIDENTIAL

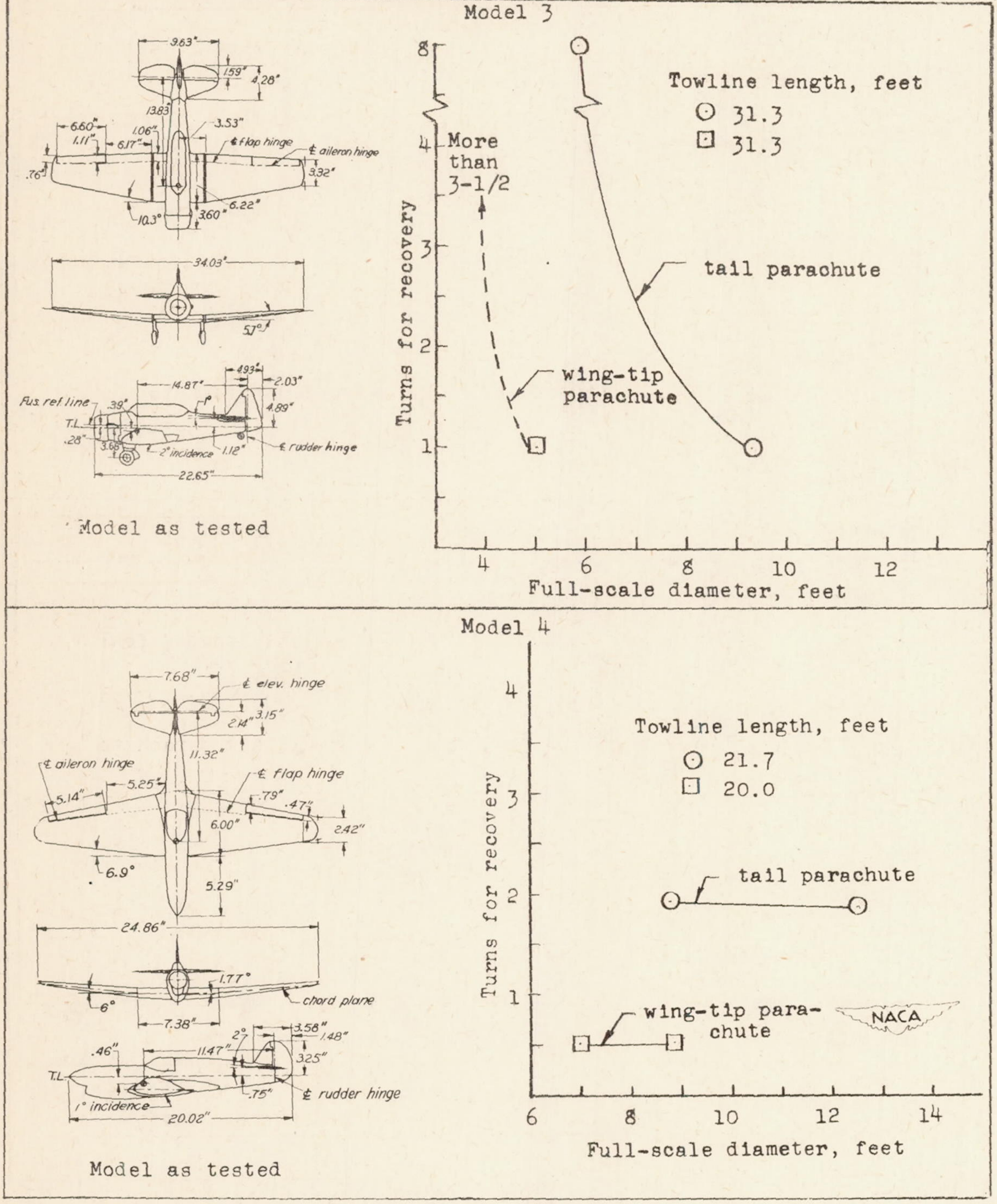


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

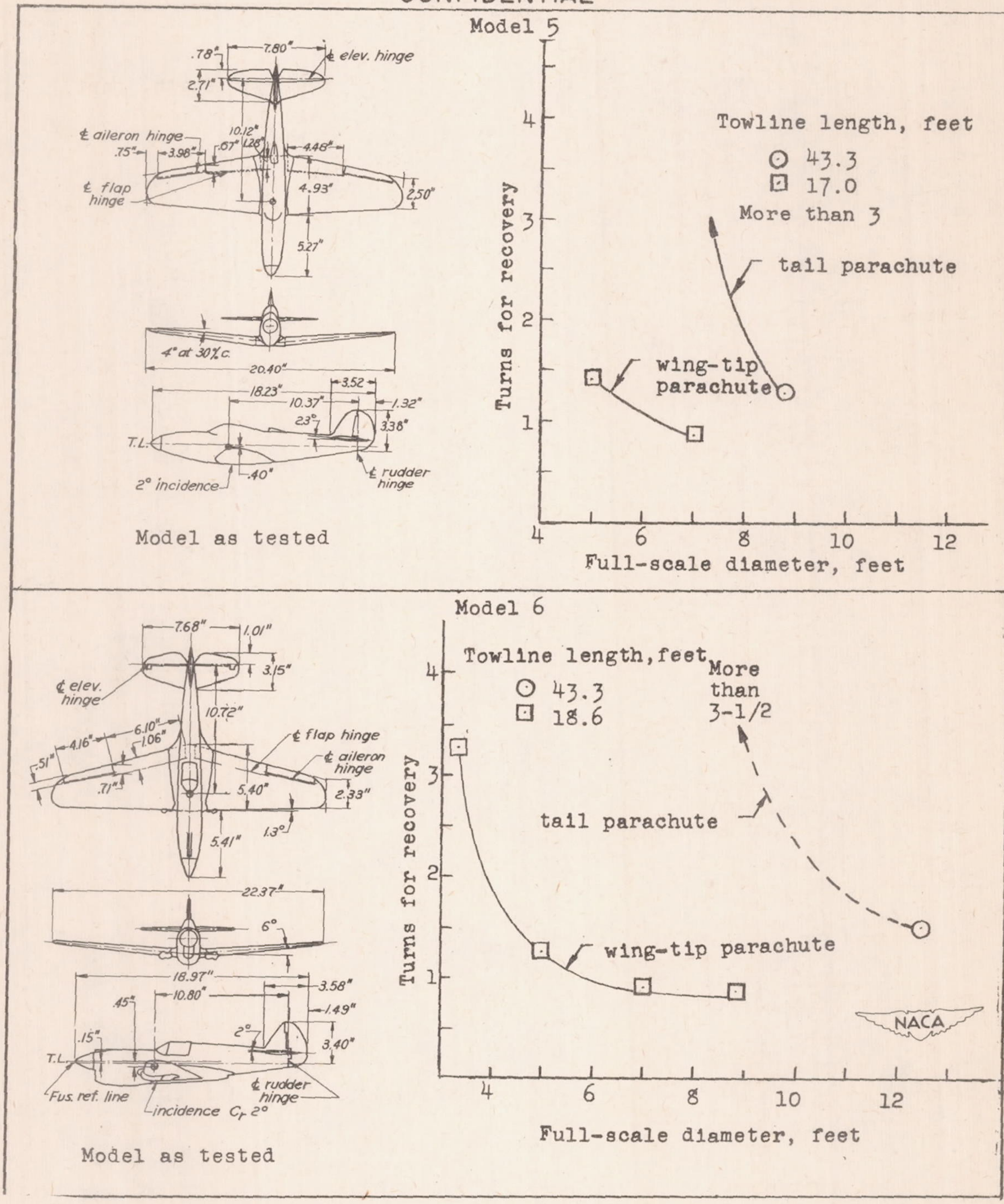


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

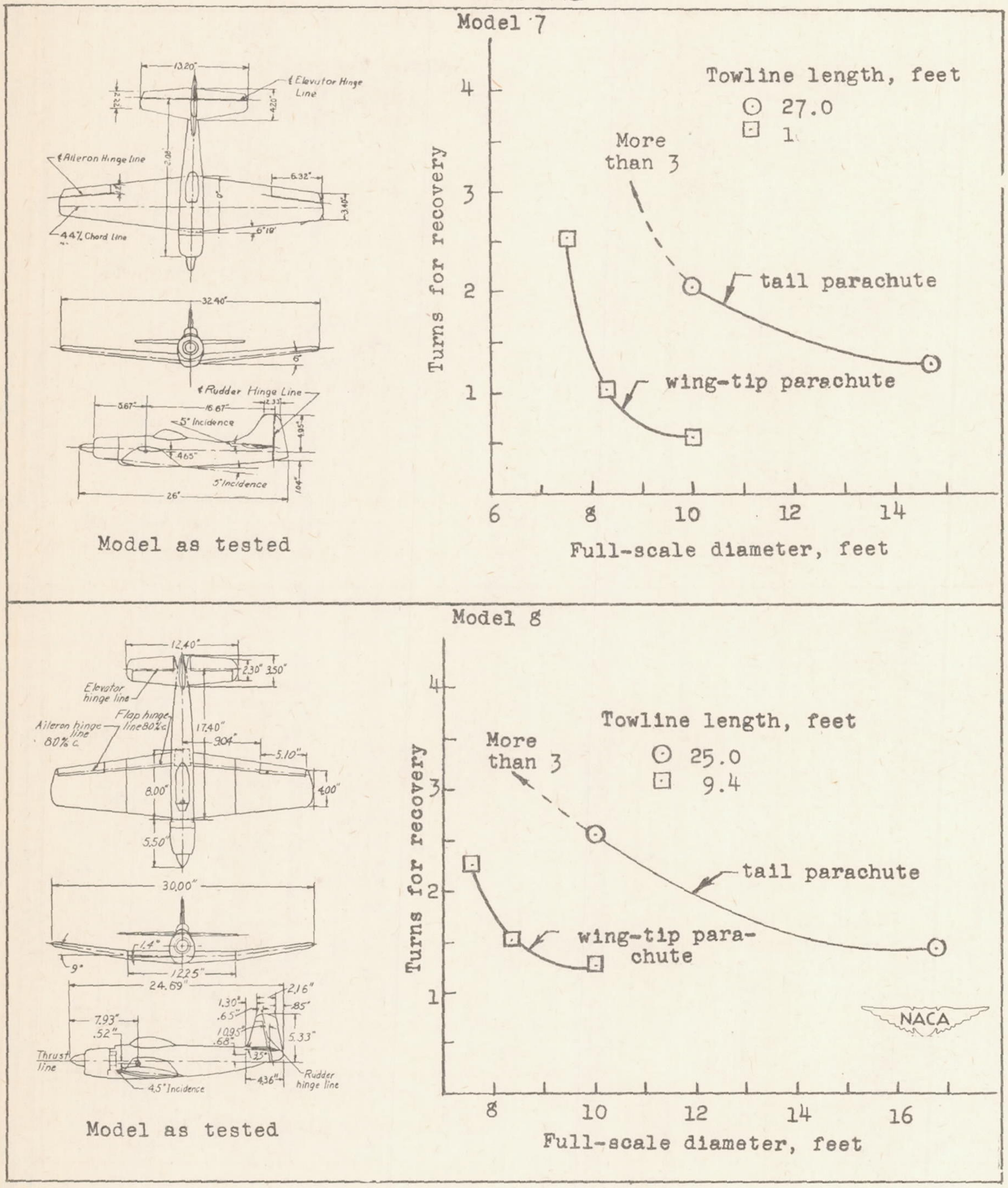


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

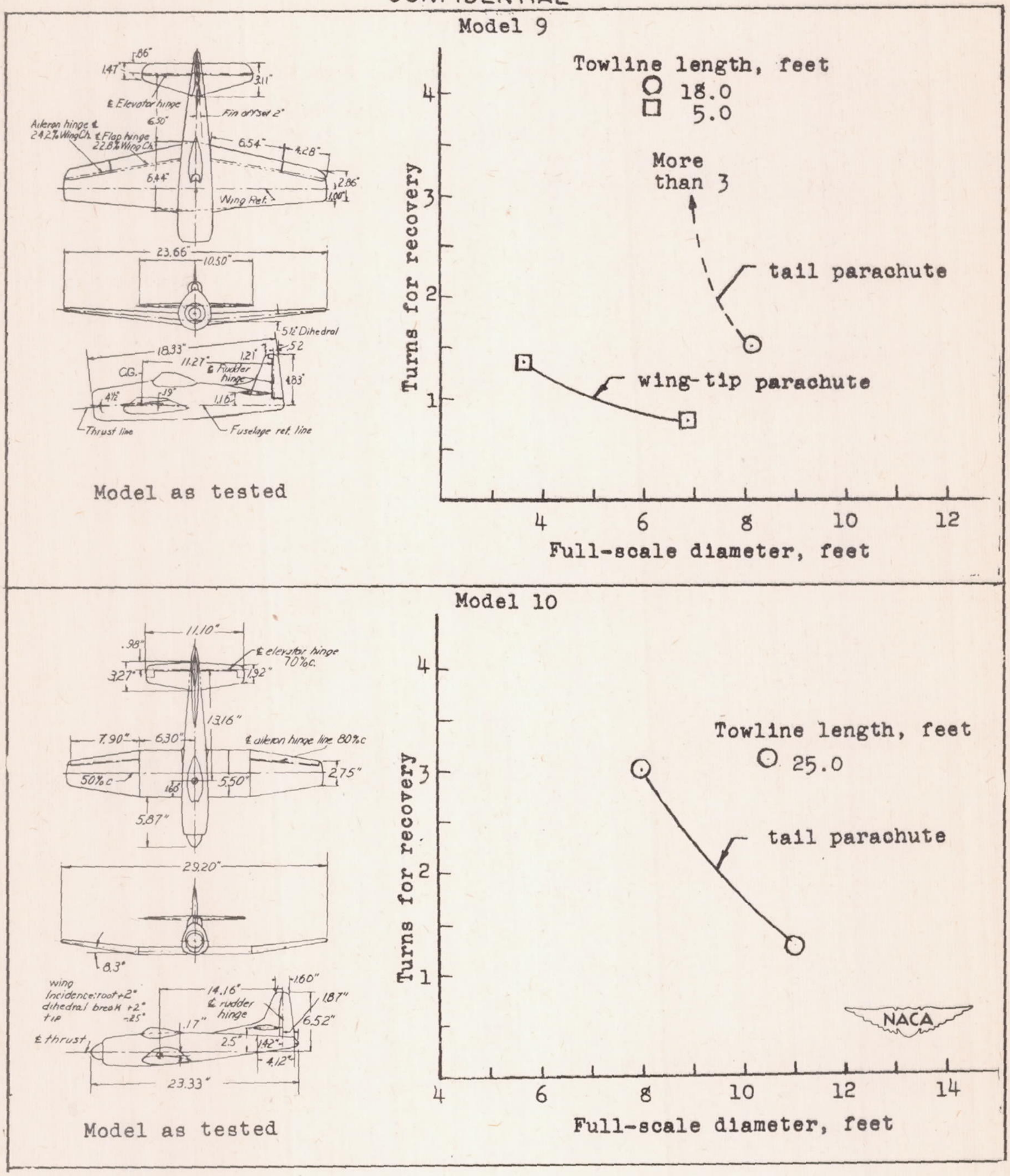


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

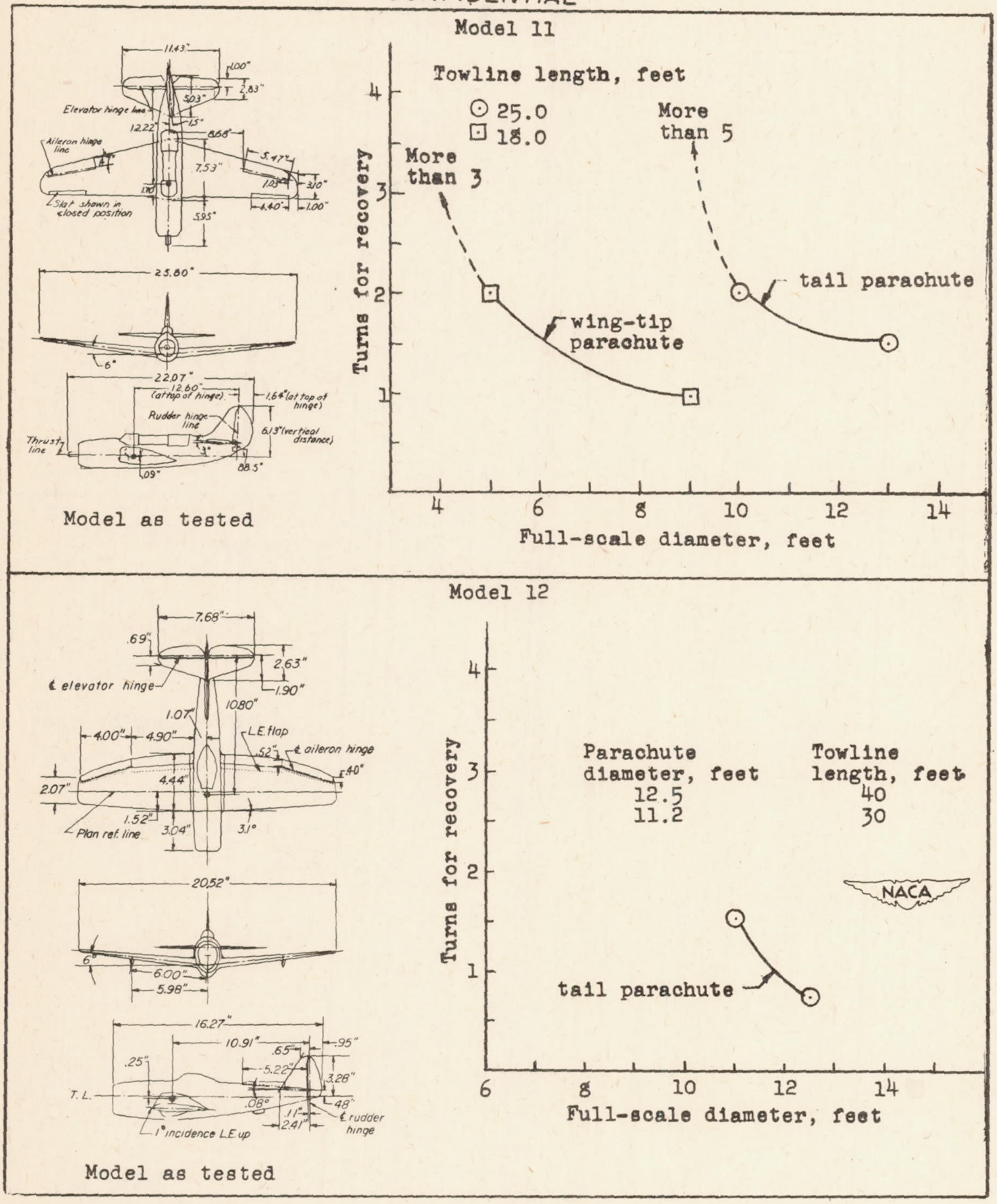


Figure 5.- Continued.

CONFIDENTIAL

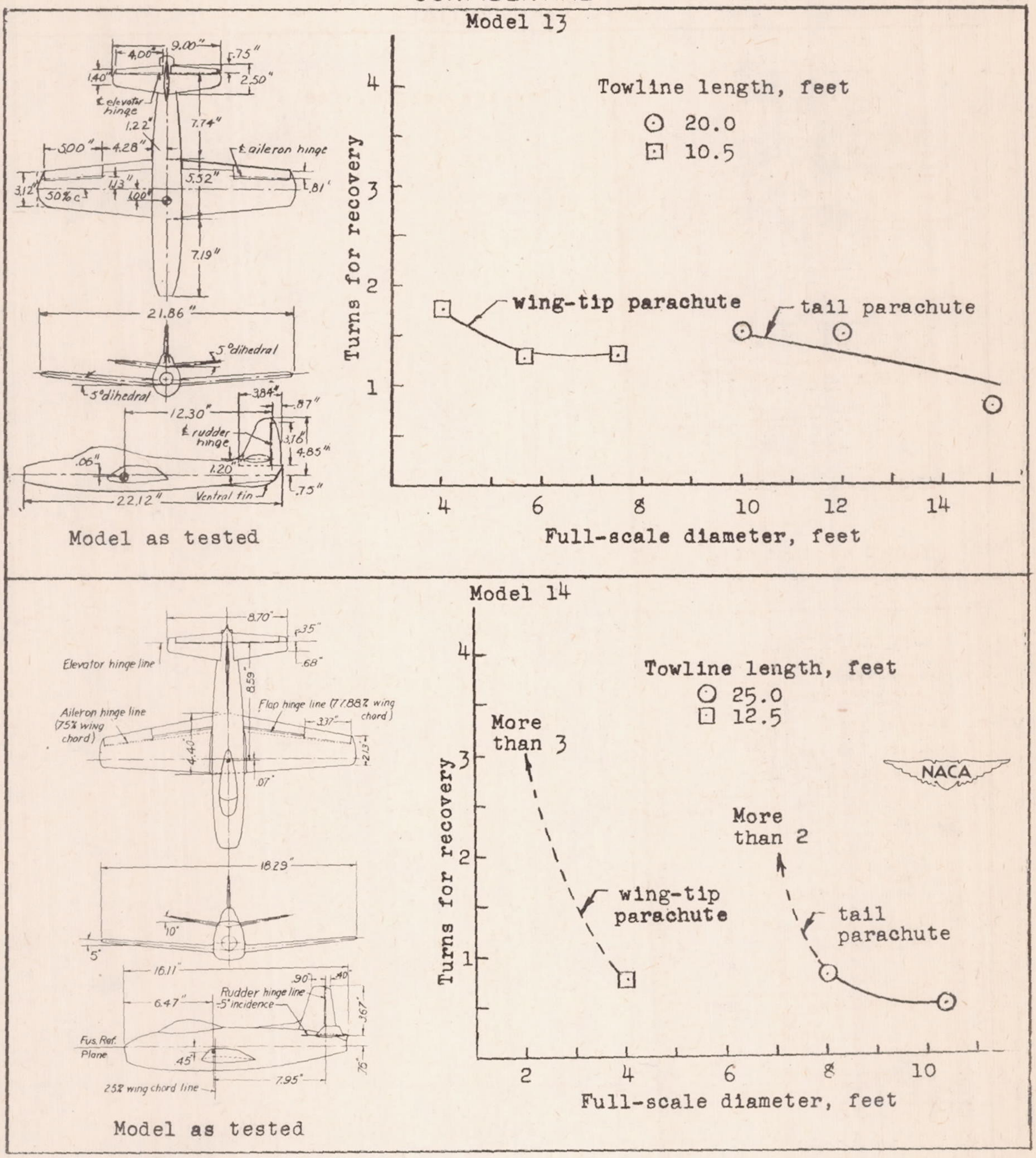


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

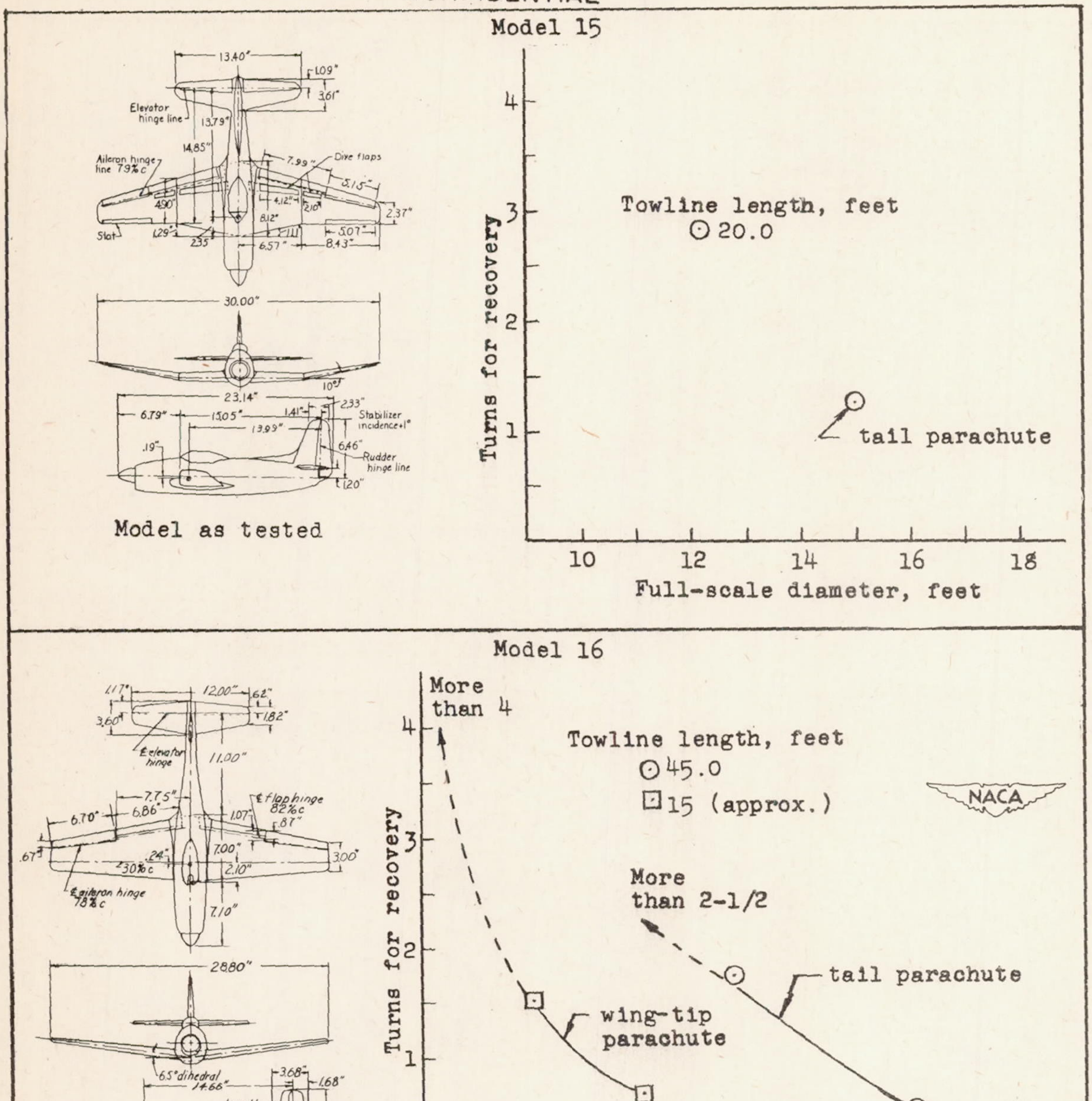


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

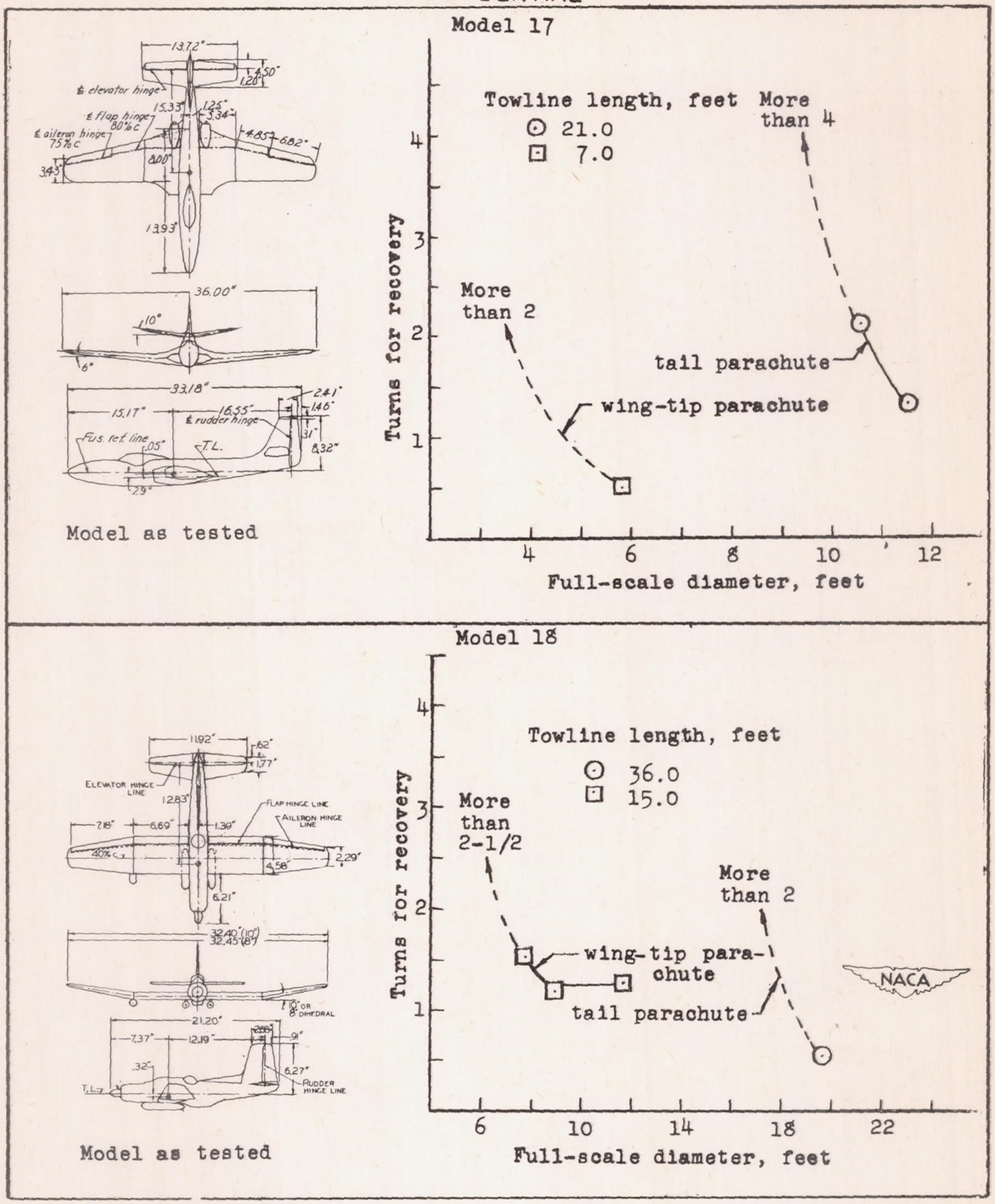


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

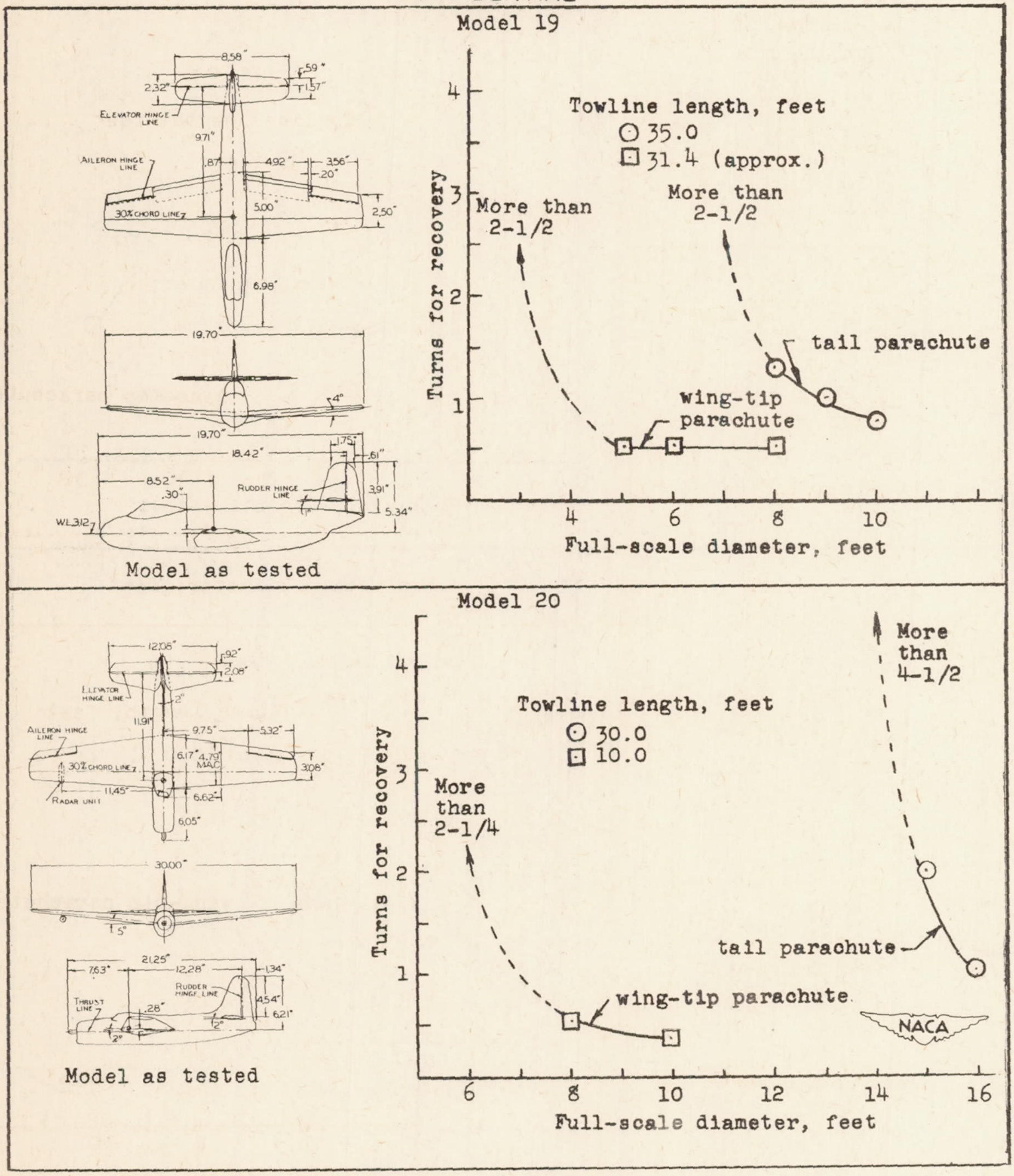


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

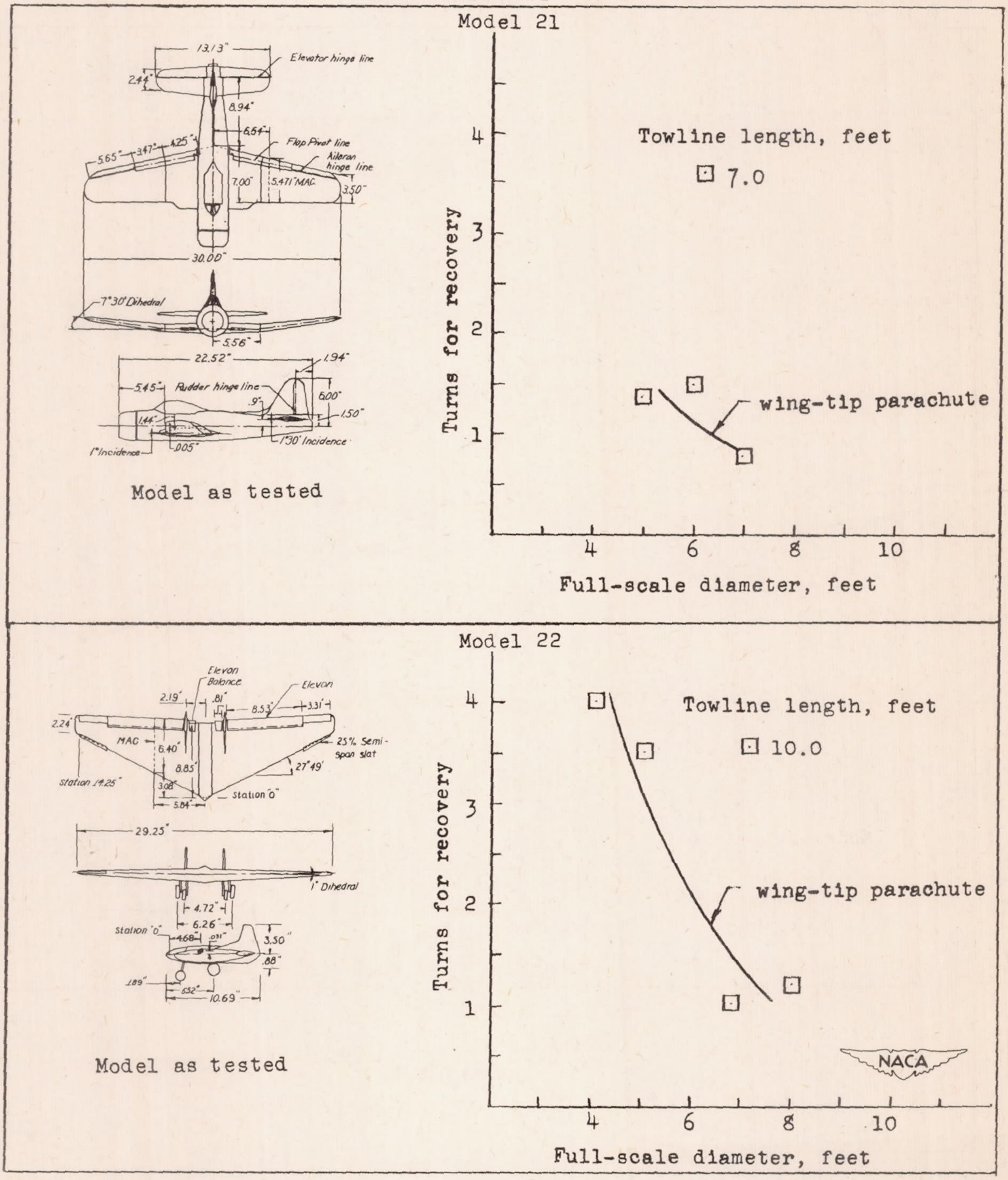


Figure 5.- Continued.

CONFIDENTIAL

CONFIDENTIAL

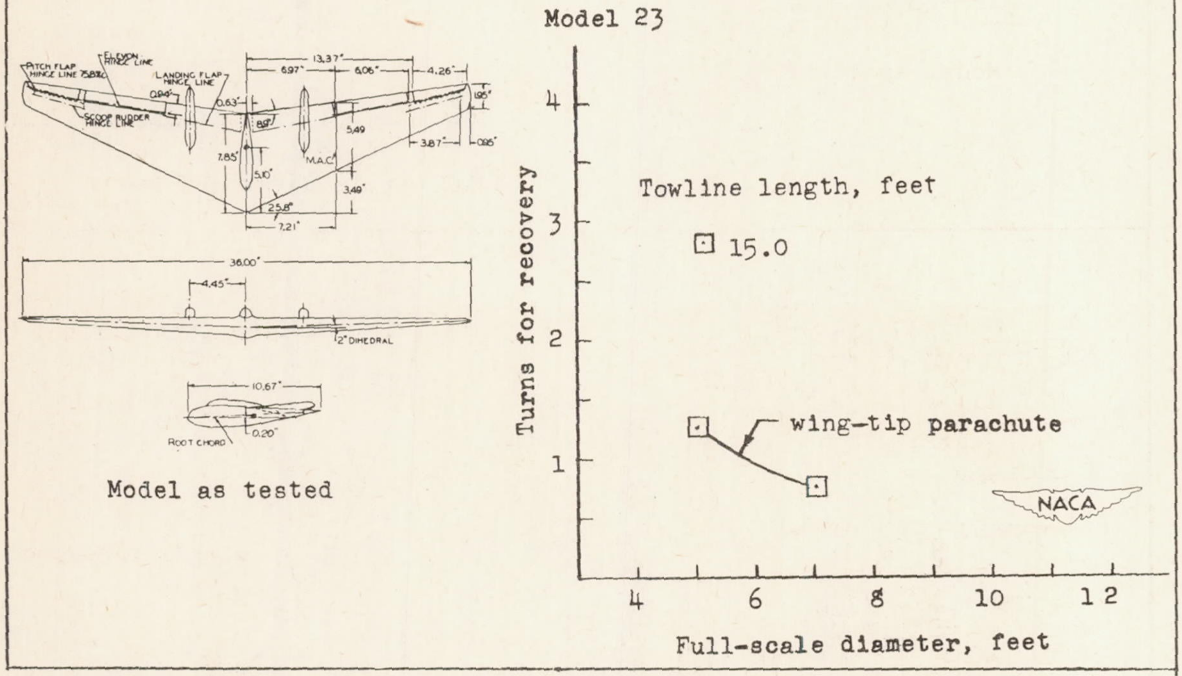
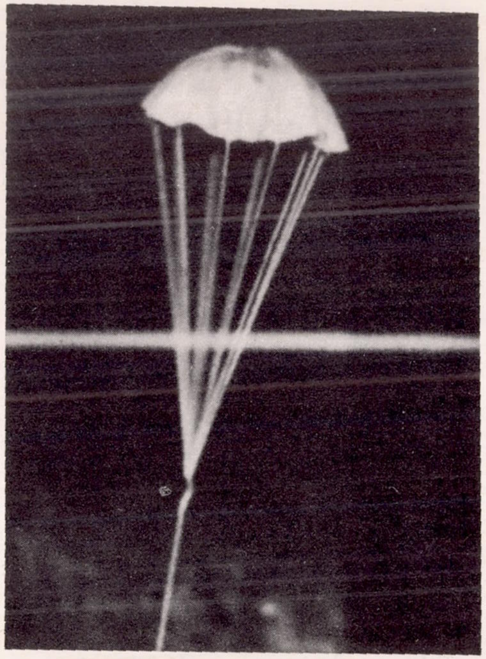
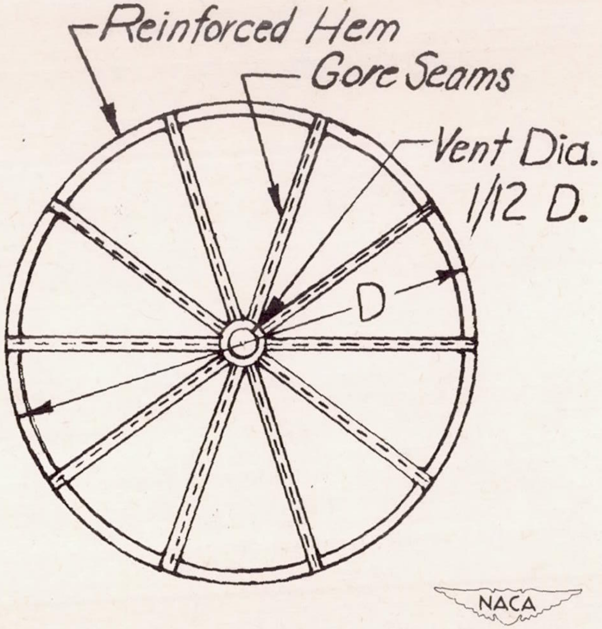


Figure 5.- Concluded.



L-41152.1

(a) Photograph of model parachute.



(b) Construction details of the model parachute. Sketch is of the parachute spread out on a flat surface.

Figure 6.- Model of a typical full-scale 10-panel, flat-type parachute.

CONFIDENTIAL

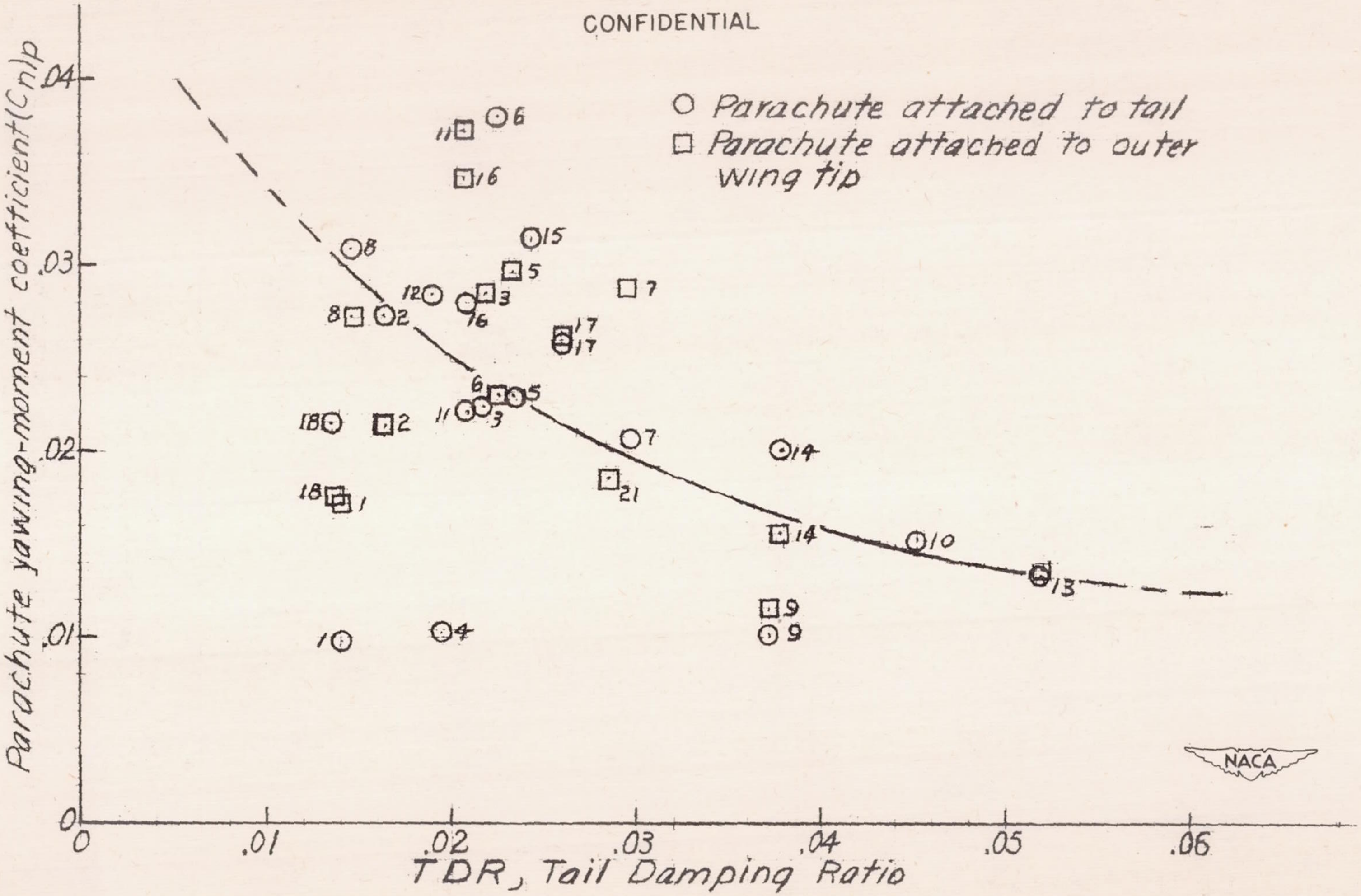


Figure 7.- The variation of parachute yawing-moment coefficient $(C_n)_p$ required for satisfactory recovery from the spin by parachute action alone with the tail-damping ratio TDR of the airplane.

CONFIDENTIAL

[redacted]

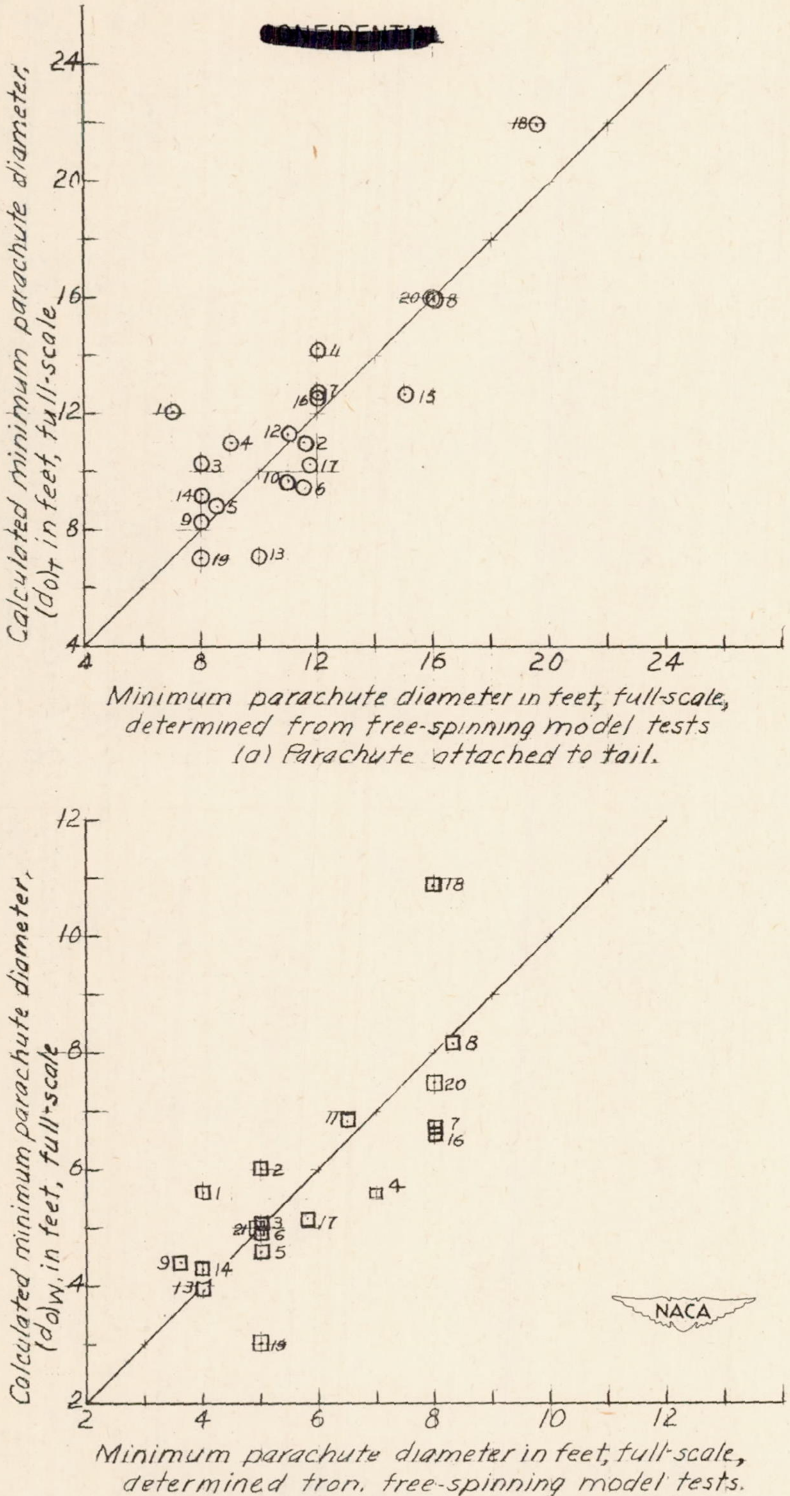


Figure 8.- Comparison of calculated minimum parachute diameter with the minimum parachute diameter determined from free-spinning model tests for 18 conventional type airplane models.

[redacted]