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No. 807

SPIN TESTS OF TWO MODELS OF A LOW-WING MONOPLANE TO INVESTIGATE SCALE EFFECT IN THE MODEL TEST RANGE

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SPIN TESTS OF TWO MODELS OF A LOW-WING MONOPLANE TO INVESTIGATE SCALE EFFECT IN THE MODEL TEST RANGE

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SUMMARY

Concurrent tests were performed on a 1/16- and a 1/20-scale model (wing spans of 2.64 and 2.11 ft, respectively) of a modern low-wing monoplane in the NACA 15-foot free-spinning wind tunnel. Results are presented in the form of charts that afford a direct comparison between the spins of the two models for a number of different conditions.

Qualitatively, the same characteristic effects of control disposition, mass distribution, and dimensional modifications were indicated by both models. Quantitatively, the number of turns for recover and the steady-spin parameters, with the exception of the inclination of the wing to the horizontal, were usually in good agreement.

The results presented indicate that, within the range of Reynolds numbers used in the present investigation, such factors as difficulty of ballasting and testing are more important in determining proper model size than the changes in scale effect likely to result from the use of different sizes of models.

INTRODUCTION

The size of models used for testing in the NACA free-spinning wind tunnel is usually dictated by considerations of tunnel operating technique and ease of ballasting. With large models the actual testing is often difficult; with small models the proper mass or inertial balance is difficult to obtain. In general, the particular choice of model size is somewhat arbitrary because usually more than one size can be tested. It was therefore considered expedient to determine to what extent the experimental results vary with the actual size of the model tested.

At the present time, little information is available concerning the effect of size or scale within the model test range on the spin characteristics of dynamic scale models. With the exception of a British report (reference 1), which contains some rolling-balance results for two similar models, and of reference 2, which mentions the effect of scale on the data obtained from the spinning balance, previous scale-effect investigations have been concerned with the comparison of model results and full-scale results.

This paper presents the results of an investigation made in the NACA free-spinning wind tunnel to compare the spin characteristics of a 1/16- and a 1/20-scale model of a modern low-wing monoplane. The investigation included a comparison of results for the steady-spin and the recovery characteristics of the two models as regards the effects of control disposition, mass distribution, and dimensional modifications.

SYMBOLS

I_X, I_Y, I_Z	moments of inertia about model body axes, X, Y, and Z, respectively
b	span
c	mean aerodynamic chord of wing
x/c	ratio of distance of center of gravity back of leading edge of mean aerodynamic chord to mean aerodynamic chord
z/c	ratio of distance of center of gravity below thrust line to mean aerodynamic chord
α	angle of attack
V	air speed
ϕ	angle of span (Y) axis to horizontal (positive when right wing is below the horizontal)
R_A	Reynolds number of full-scale airplane
R_M	Reynolds number of model

N scale of model (1/16, 1/20, etc.)

δ_e elevator deflection (positive up)

Ω resultant angular velocity

APPARATUS AND MODELS

The tests were performed in the NACA 15-foot free-spinning wind tunnel, as described in reference 3.

A 1/16- and a 1/20-scale model of a modern low-wing monoplane trainer with fixed landing gear were tested. The wing spans of the models were 2.64 and 2.11 feet, respectively. Photographs of the models are shown in figure 1. The models were constructed principally of balsa. For both models, wing and tail-surface contours were held to their true dimensions to within ±0.01 inch; all other dimensions under 6 inches were held to within ±0.02 inch; all other dimensions over 6 inches were held to within ±0.05 inch; and angular relationships, such as wing setting, sweepback, and control settings, were held to within $\pm 0.5^{\circ}$.

Lead ballast added at suitable locations served to bring the weight, the moments of inertia, and the center-of-gravity locations to their appropriate values. A clockwork mechanism was installed on each model to hold the controls in position during the steady spins and to actuate the controls during the recovery tests. The weights, the moments of inertia, and the center-of-gravity positions of the two models were held to their true scaled-down full-scale values within the following limits:

Weight, percent	±1
Center-of-gravity position, percent M.A.C.	±1
Moments of inertia, percent:	
1/20-scale model	
I_X	-1 to 5
I_Y	-1 to 5
I_Z	-6 to 0

1/16-scale model

I_X	-3 to 3
I_Y	0 to 6
I_Z	1 to 7

The maximum control displacements used during the tests were ±30° for the rudder, 30° up and 20° down for the elevator, and 30° up and 17° down for the ailerons.

TEST CONDITIONS AND METHODS

Tests were performed with the two models representing the same equivalent full-scale conditions. The normal model loading conditions corresponded, within the limits of accuracy previously indicated, to the following full-scale mass distribution. This mass distribution is considered to be typical of a modern low-wing monoplane.

Weight, lb	4340
x/c	0.248
z/c	0.126
I_X, slug-ft^2	2479
I_Y, slug-ft^2	3876
I_Z, slug-ft^2	5776

The model tests were performed under conditions that were equivalent to spinning the full-scale airplane at an altitude of 7000 feet.

Tests were performed on the two models to compare the effect of changing the mass distribution. The particular mass variation investigated consisted in increasing the moments of inertia I_Y and I_Z by 30 percent of I_Y. This loading was obtained on the models by extending weights along the fuselage; it is hereinafter referred to as the "modified" loading condition.

Tests were conducted to determine the effect of dimensional modifications on both the normal and the modified loading conditions. Two auxiliary fins of the size and location shown in figure 2 were tested independently on the two models.

Concurrent tests were run on the two models in each test condition for various control dispositions. The results of the investigation are presented in figures 3 to 8. In order to permit a direct comparison of effects due to differences in size, the steady-spin parameters presented in the figures (determined by methods described in reference 3) have been converted to the corresponding full-scale values. If each model gave a similar representation of the motion of the airplane, the results for the two models as plotted on the figures would be identical. The angle of sideslip is approximately equal to ϕ minus the helix angle (angle between flight path and vertical). For the recorded spins, the helix angle averaged about 5.5° for both models.

Recoveries were measured by the number of turns the spinning model made from the instant the controls were observed to move until the spinning rotation ceased.

For convenience, the results are presented in two sections. The first section contains a comparison of the model results for the normal loading condition, including dimensional modification on the models; the second section presents a similar comparison of the models in the modified loading condition (I_Y and I_Z increased by 30 percent of I_Y). All the results are for right spins.

In several instances comparable data on the two models are lacking, particularly for spins involving upward settings of the elevators, because these spins were too difficult to hold in the tunnel.

In a comparison of the number of turns required for recovery, it should be remembered that, for an oscillatory spin, recoveries depend somewhat on the phase of the oscillation at which the controls are manipulated and that, for such spins, it is difficult to obtain consistent results. This effect may account for a difference of one-half turn or more in recovery results for oscillatory spins.

PRECISION

The precision of the measurement made in the spin tunnel is believed to be within the following limits:

Velocity V, percent	±2
Angular velocity Ω, percent	±1
Angle of attack α, deg	±3
Angle of wing to horizontal ϕ, deg	±2
Turns for recovery	±1/4

The preceding limits may be exceeded in instances where it is difficult to handle the spin in the tunnel owing to a high rate of descent or to the wandering or oscillatory nature of the spin.

RESULTS FOR NORMAL LOADING CONDITIONS

Normal Flying Condition (Fig. 3)

Qualitative comparison of trends indicated by each model.- In the normal loading and the normal flying conditions, both models exhibited similar characteristics. With the ailerons neutral, raising the elevator from neutral generally steepened the spins, increased the vertical velocity, slightly decreased the angular velocity, tended to lower the right (inboard) wing, and tended to improve recovery. Ailerons with the spin effected similar changes in the steady spins except that the angular velocity increased instead of decreasing. Ailerons against the spin tended to flatten the spin slightly and to produce more critical oscillatory spins. Neither model would spin steadily with the rudder neutral and no results are presented for this control setting.

Quantitative comparison of results for the two models.- A study of figure 3 reveals that the results for the two models are in general quantitative agreement in regard both to steady-spin parameters and to turns for recovery except for spins with the ailerons set full with the spin. With this aileron disposition, the 1/20-scale model spun steeper, faster, steadier, and with its right wing from 7° to 14° higher than that of the 1/16-scale model. The large change in ϕ with aileron setting should be noted. (See figs. 3(h) and 3(i).)

Fin 1 in Place (Fig. 4)

Qualitative effect of the fin as shown by both models.- The effect of fin 1 forward of the vertical tail was small and inconsistent. With the ailerons neutral and the elevator down, both models gave flatter spins with the added fin area. With raised elevator, however, the effect on either model was slight. Ailerons with the spin resulted in steeper spins; whereas ailerons against the spin produced more oscillatory and irregular spins. The corresponding velocities, however, did not appear to vary consistently with angle of attack.

Quantitative comparison of results for the two models.- The wandering and the oscillatory nature of the spins, particularly when the ailerons were used, makes a rigorous comparison between the two models difficult. With the ailerons neutral, however, both the steady-spin parameters and the recoveries are in fairly close agreement, excepting the velocities that accompanied the spins with the elevator 20° down. The tendency of the 1/20-scale model to spin with its right wing higher than that of the 1/16-scale model, when the ailerons are with the spin, should be noted. The two types of spin exhibited by the 1/20-scale model with the ailerons against the spin (fig. 4(c)) should also be observed.

Fin 2 in Place (Fig. 5)

Qualitative effect of the fin as shown by both models.- In general, both models indicate a favorable effect of adding area below the horizontal tail. With neutral ailerons the spins were slightly steeper and the recoveries faster, although the information on the 1/16-scale model is limited. Ailerons with the spin produced steep spins similar to those obtained without the added fin area. With the ailerons against the spin, neither model would spin consistently.

Quantitative comparison of results for the two models.- Oscillatory spins and fluctuating air speeds make comparison of the results for the two models difficult, particularly as regards the velocity and the inclination of the wings to the horizontal. With the ailerons neutral, however, the other parameters are in good agreement. For the ailerons with the spin, the 1/20-scale model definitely spun steeper, faster, and with its right wing considerably higher (10° to 14°) than that of the 1/16-scale model.

RESULTS FOR MODIFIED LOADING CONDITIONS

(I_Y AND I_Z INCREASED BY 30 PERCENT I_Y)

Normal Flying Condition (Fig. 6)

Qualitative effect of the change in loading.- Both models were similarly affected by the change in loading. The effect of the modified load on both models was to flatten the spin, decrease the rate of descent, and decrease the rate of rotation, for all control dispositions except those involving the ailerons set with the spin. With this control disposition, the reverse effect on the angle of attack and the velocity was obtained, but both models were prone to spin with this aileron disposition when the elevators were down, even when the rudder was neutral (fig. 6(c)). Recoveries were not greatly different from those obtained in normal loading, but both models indicated a slight adverse effect of the modified loading.

Quantitative comparison of results for the two models.- Quantitatively, the results for the two models in the normal flying condition check well; the greatest discrepancies occur for the ailerons with the spin and the elevator neutral. An examination of figure 6(i) indicates that, for the ailerons with the spin, the 1/20-scale model tended to spin with its right wing higher than that of the 1/16-scale model.

Fin 1 in Place (Fig. 7)

Qualitative effect of the fin as shown by each model.- A comparison of figures 6 and 7 indicates that the detrimental effect of the added fin area was quite pronounced when the models were in the modified loading condition.

The presence of the fin caused both models to spin flatter and at a lower velocity and increased the number of turns for recovery. For the ailerons with the spin, however, the effects were not very definite.

Quantitative comparison of the results for the two models.- With the exception of the spins in which the ailerons were with the spin, the steady-spin parameters and recoveries for the models with fin 1 are in good agreement; the largest discrepancy appears in figure 7(o).

For the ailerons with the spin, elevators down, the 1/20-scale model spun flatter, at a lower air speed, and with its right wing 5° higher, than the 1/16-scale model. It should be observed, however, that occasionally a steeper spin was obtained with the 1/20-scale model, but no quantitative data could be secured (fig. 7(c)).

Fin 2 in Place (Fig. 8)

Qualitative effects of the fin as shown by each model.- A comparison of figure 5 (normal load) and figure 8 (modified load) reveals that, with the additional fin in place, the effect of the modified loading on both models was, in general, an increase in angle of attack, a decrease in vertical velocity, a decrease in angular velocity, and an increase in turns for recovery, for all control dispositions not involving ailerons with the spin. For the ailerons with the spin, the modified loading appeared favorable.

A comparison of figures 6 and 8 indicates that, for the models with the modified loading, the addition of the auxiliary fin below the fuselage tended to increase the rate of descent but had little other effect.

Quantitative comparison of the results of the two models.- With the ailerons either neutral or against the spin, the 1/20-scale model spun slightly flatter than the 1/16-scale model for all elevator settings, but the differences in the other parameters were small. For the ailerons with the spin, a comparison can be made only for the elevator-down spins. With this control disposition, the velocity of the 1/20-scale model was greater and its right wing was a few degrees higher than that of the 1/16-scale model.

DISCUSSION

Reynolds Number Range Covered by Investigation

The relationship between the test Reynolds number of a dynamically similar scale model tested in air of normal density and the Reynolds number of the full-scale airplane can be expressed as follows:

$$R_M = R_A N^{3/2}$$

For the 1/20- and the 1/16-scale models used in these experiments, the foregoing relationship becomes

$$R \text{ for } 1/20\text{-scale model} = R_A(1/20)^{3/2} = 0.011R_A$$

$$R \text{ for } 1/16\text{-scale model} = R_A(1/16)^{3/2} = 0.0156R_A$$

The range of Reynolds numbers investigated - based on the mean wing chord, a mean value of the kinematic viscosity of 0.000165 foot^2 per second, and the measured rates of descent - is tabulated below:

Test		Model R	Corresponding full-scale R
Minimum	1/20 model	62,500	5,680,000
	1/16 model	91,400	5,850,000
Maximum	1/20 model	113,500	10,280,000
	1/16 model	148,000	9,480,000

Because of the turbulence in the tunnel, the effective Reynolds number is greater than the Reynolds number of the test model by a factor 1.8 (reference 4). The effective test Reynolds number thus ranged from 112,500 (for the 1/20-scale model) to 266,400 (for the 1/16-scale model).

Correlation between Results for the Two Models

On the basis of the information contained in figures 3 to 8, the following conclusions have been reached:

1. The same qualitative effects of control disposition, mass distribution, and dimensional modifications were indicated for the two models.

2. The most difficult spins to correlate were those involving aileron deflections. When the ailerons were with the spin, the 1/20-scale model generally spun steeper in the normal loading condition than the 1/16-scale model. In the modified loading condition, although there was generally little difference in results for the two models, spins were obtained for which the reverse was true. For the ailerons against the spin, there existed a tendency for the 1/16-scale model to spin steeper than the 1/20-scale model, regardless of the mass distribution.

3. All of the steady-spin parameters were in fair agreement with the exception of the angle of the wing to the horizontal, which varied considerably for the two models, particularly when the ailerons were used. In general, when the ailerons were with the spin, the 1/20-scale model tended to spin with the right wing higher than that of the 1/16-scale model, that is, with more outward sideslip. (It will be observed in going from the larger model to the smaller model that the change in angle of sideslip was in the same direction as that found in going from full-scale data to model data in reference 2.)

4. The size of the model had little influence on the number of turns for recovery, even for spins in which the angle of the wing to the horizontal was noticeably different for the two models. The relationship existing between the angle ϕ and the number of turns for recovery is exceedingly complex and, consequently, the significance of the aforementioned result is not completely understood. From a practical point of view, the number of turns for recovery is usually considered to be the most important parameter of the motion insofar as the correlation of model results and full-scale results is concerned.

Comparison with Flight Results

Spin-test results of the full-scale airplane represented by the two models are presented in reference 5. Unfortunately, the control settings used in these full-scale tests are not the same as those used on the models in this investigation, and therefore a rigorous comparison cannot be made. A qualitative comparison, however, seems to indicate that the effect of scale is of much greater significance when the results for either model are compared with the full-scale results than when the results for either model are compared with the results for the other. It would therefore appear that, within the range of the model sizes investigated, such factors as difficulty of construction and testing are more important in determining proper model size than are the changes in scale effect likely to exist between extreme sizes feasible for test in the 15-foot tunnel.

Comparison with Other Results

The investigation reported in reference 1 included a comparison of rolling-balance measurements made in a 7-foot vertical tunnel on a 1/10- and on a 1/17.5-scale model of a British fighter airplane. The resultant aerodynamic moments about the spinning axis for several rates of rotation were measured on both models for a single angle of attack (37.9°). The rates of rotation were measured by the quantity $\Omega b/2V$ and the values of this parameter ranged from 0.3 to 0.6. Similar measurements were made on the 1/17.5-scale model in a 4-foot tunnel to determine the effect of tunnel size. The tunnel effect was found to be small. The sets of measurements made in the 7-foot tunnel agreed closely with each other, but the results for either model disagreed considerably with the corresponding results for the full-scale airplane. It will be observed that this effect of scale is consistent with the comparison of the results of the present investigation with the full-scale results of reference 5.

The results in reference 2 indicate that, within the range of Reynolds numbers tested (of the same order of magnitude as the tests of the present investigation), the scale effect was negligible.

Suggestions for Future Research

In this investigation the actual difference in the size of the models used did not completely cover the greatest range of sizes likely to be encountered in spin-tunnel test work. It would therefore appear advisable to supplement the present investigation with data representative of a much greater variation in model size.

The model-recovery results in this investigation were not particularly sensitive to the modifications tried. It is suggested that, in future investigations, modifications be tested that markedly affect the recovery characteristics of the models.

CONCLUSIONS

On the basis of the results obtained in the investigation, the following conclusions can be drawn:

1. Qualitatively, the same characteristic effect of control disposition, mass distribution, and dimensional modifications were indicated for both models.

2. The number of turns for recovery, probably the most important parameter of the spin for practical purposes, were in good agreement for both models.

3. It would appear that, for the 15-foot tunnel, such factors as difficulty of construction and testing are more important in determining proper model size than are the changes in scale effect likely to exist between the different sizes of models that are practicable for the 15-foot spin tunnel. This conclusion is based entirely on the results presented in this report. The investigation should be extended to include a greater range of model sizes and more extreme modifications.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 16, 1941.

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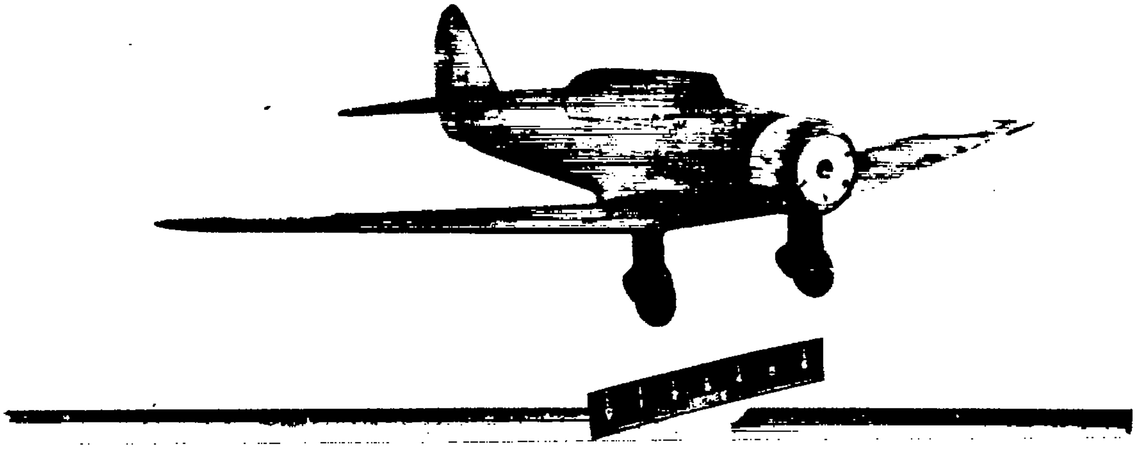
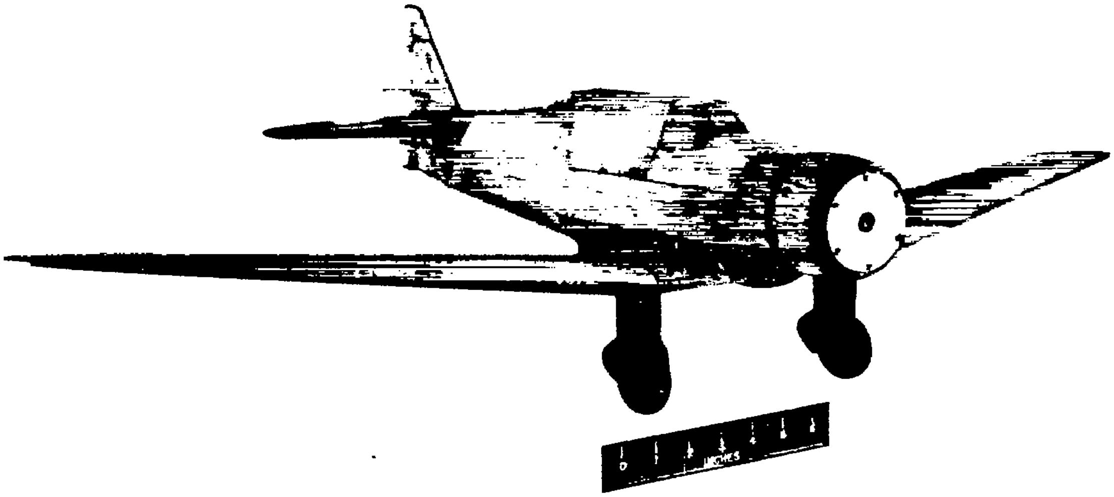


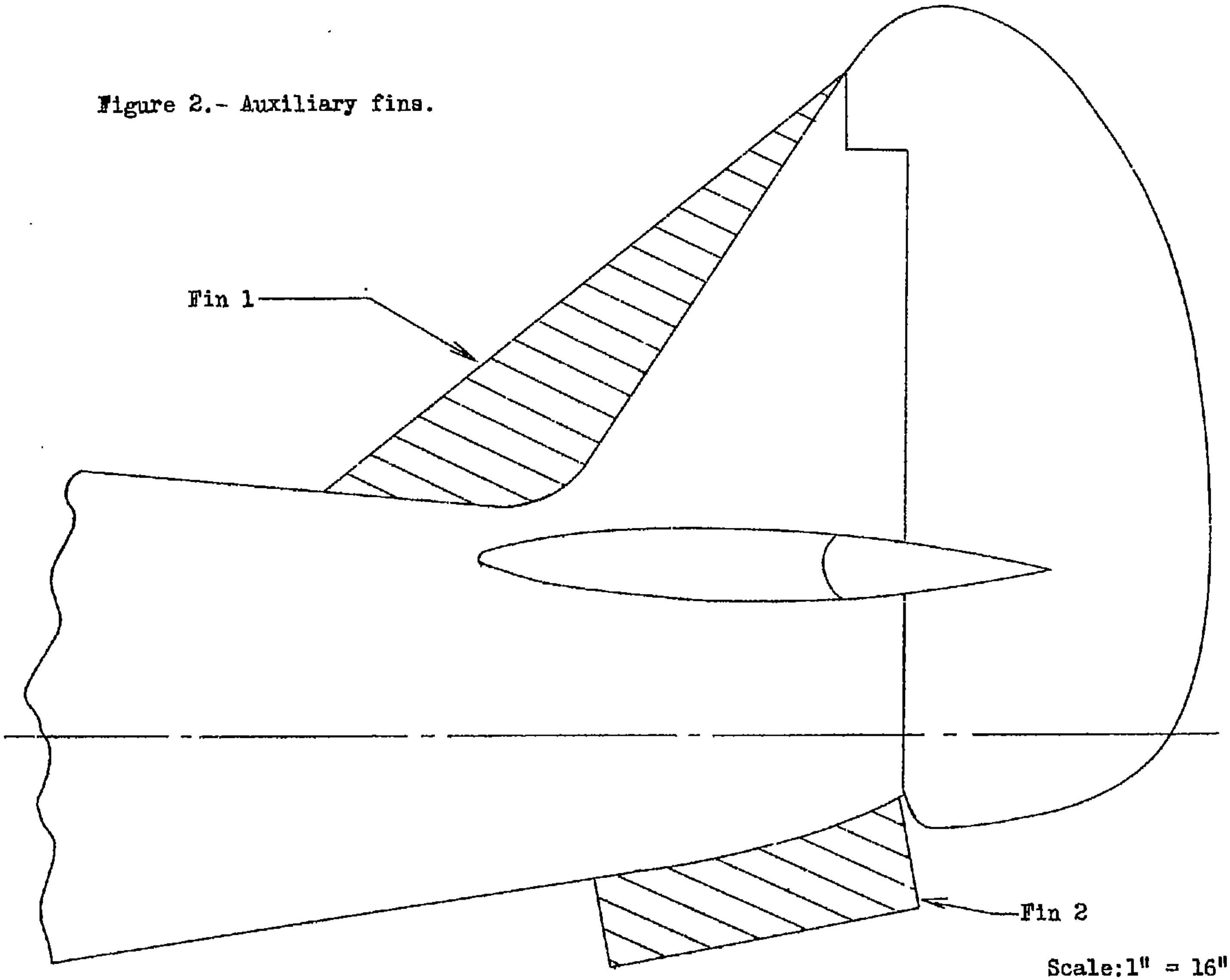
(a) The 1/20 scale model.



(b) the 1/16 scale model.

Figure 1.- Photographs of the two models used in the investigation.

Figure 2.- Auxiliary fins.



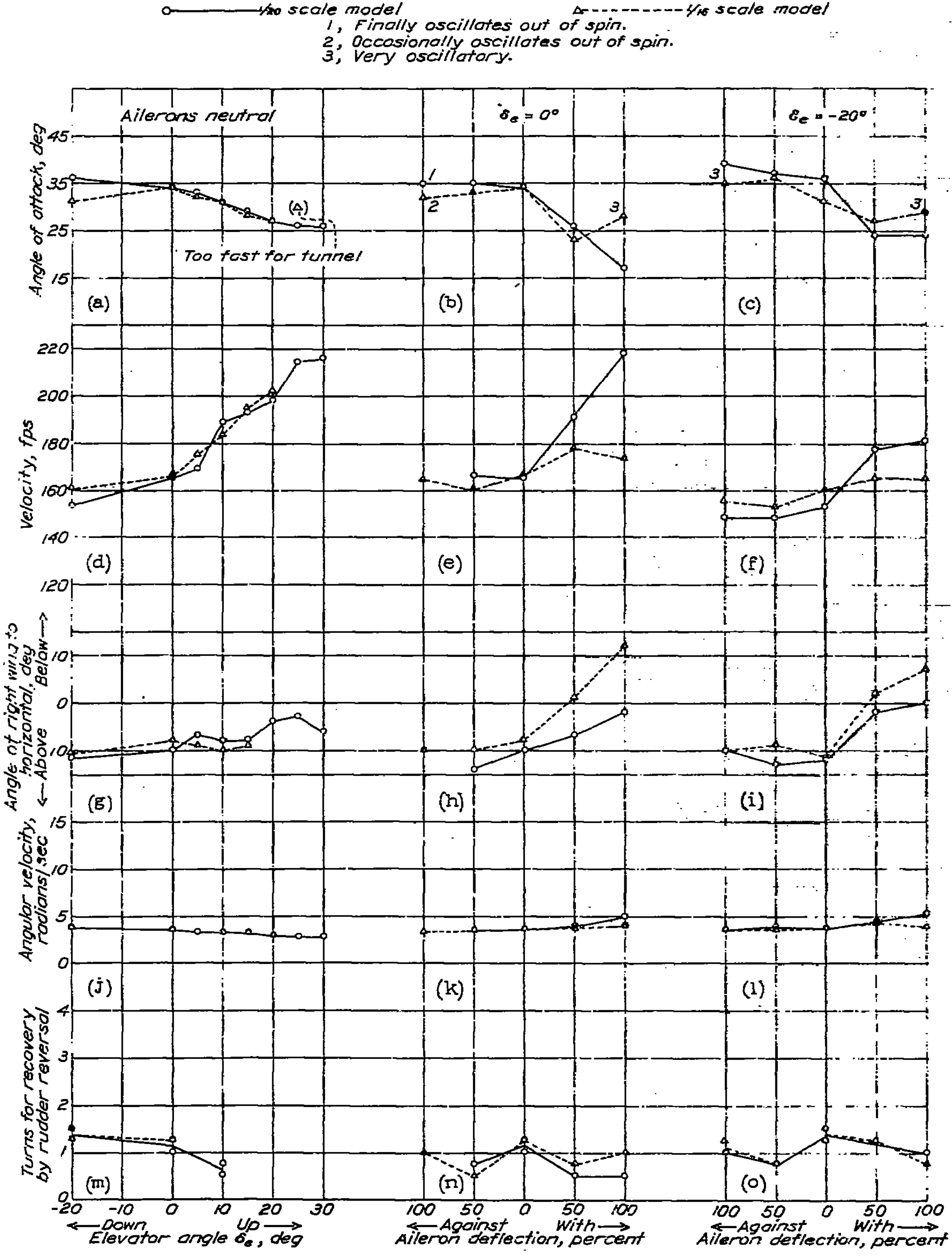


Figure 3.- Effect of scale on two models in the NACA 15-foot free-spinning wind tullel. Normal load; rudder 30° with spin; right spins.

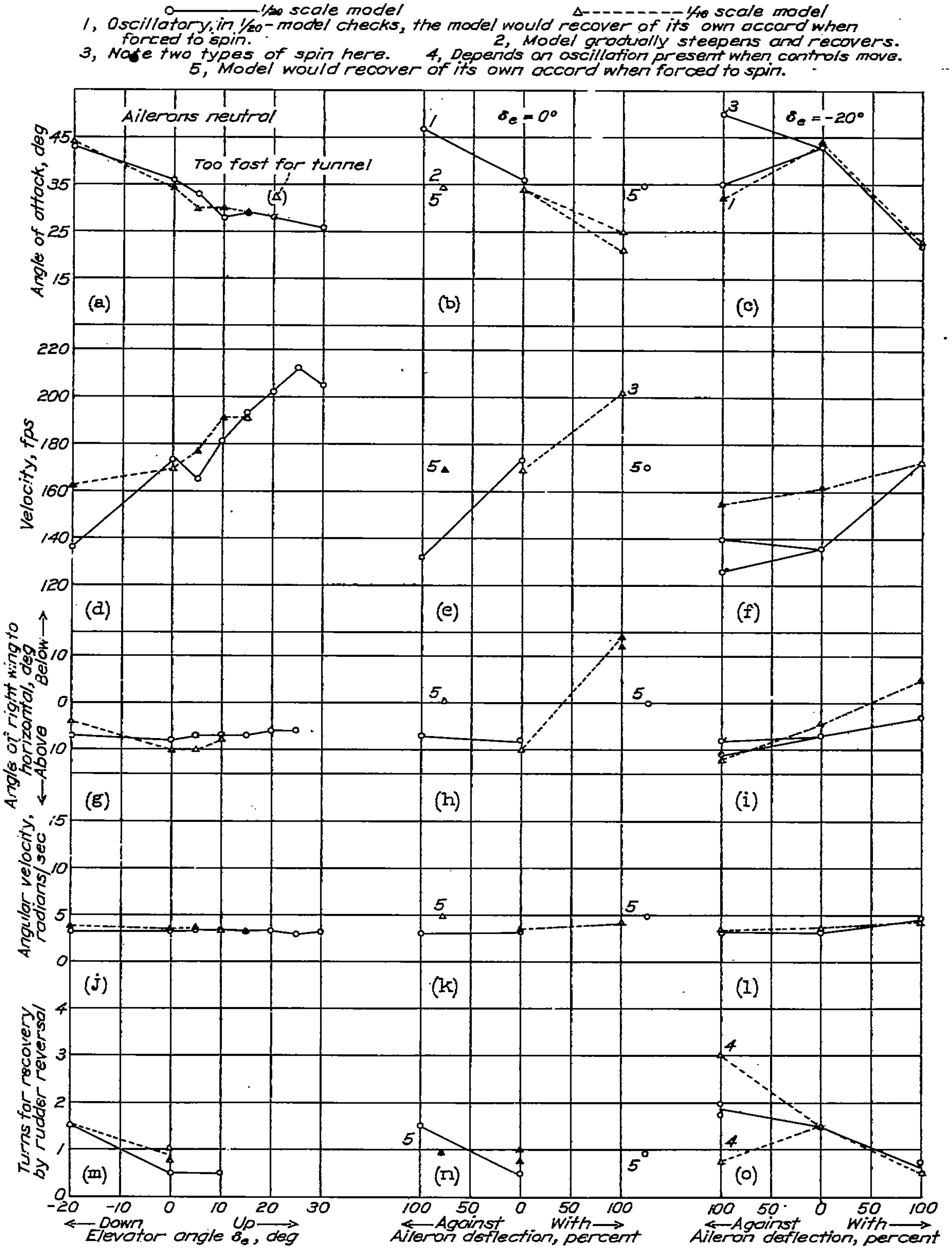


Figure 4.- Effect of scale on two models in the NACA 15-foot free-spinning wind tunnel. Normal load; auxiliary fin 1 in place; rudder 30° with spin; right spins.

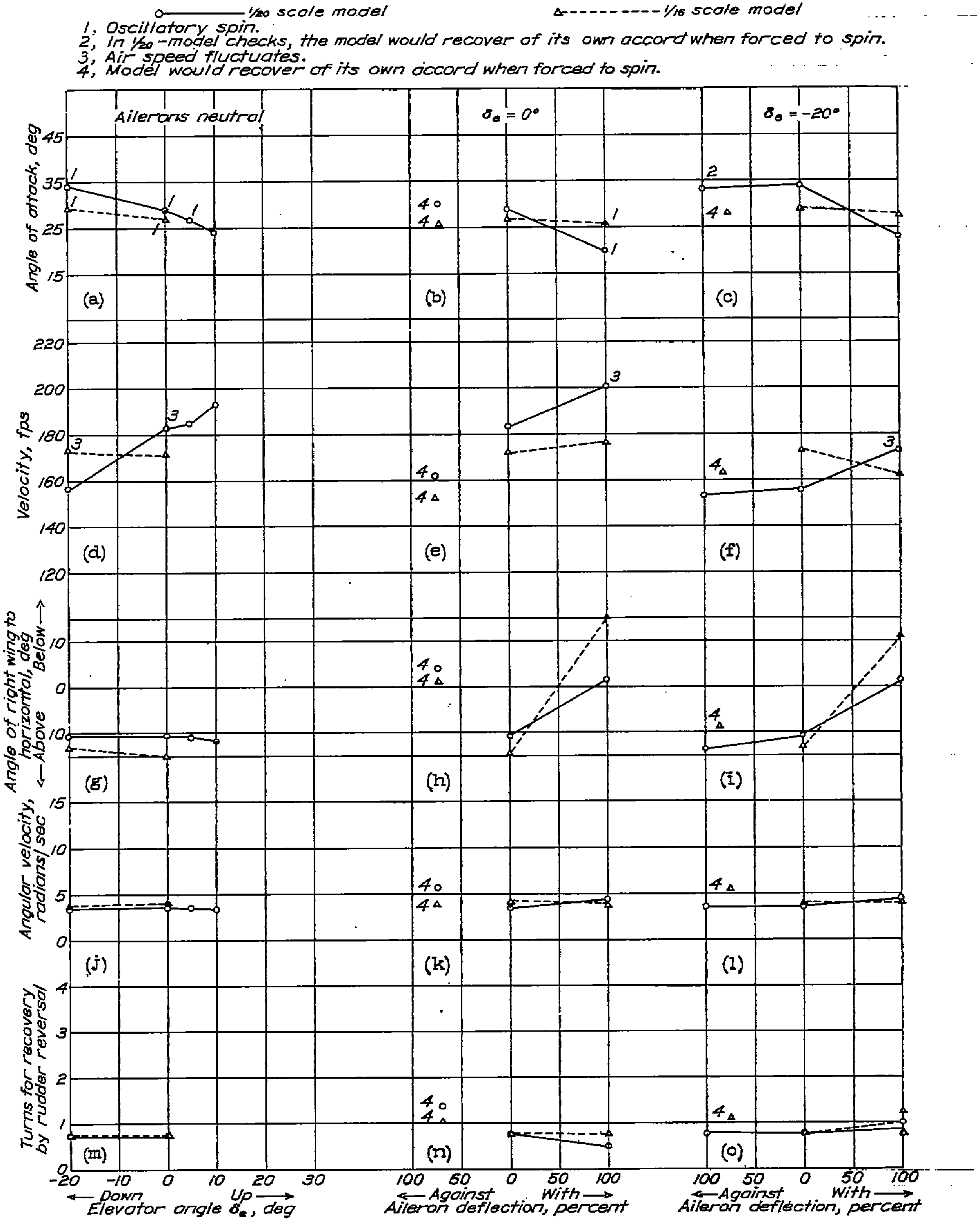


Figure 5.- Effect of scale on two models in the 15-foot free-spinning wind tunnel. Normal load; auxiliary fin 2 in place; rudder 30° with spin; right spins.

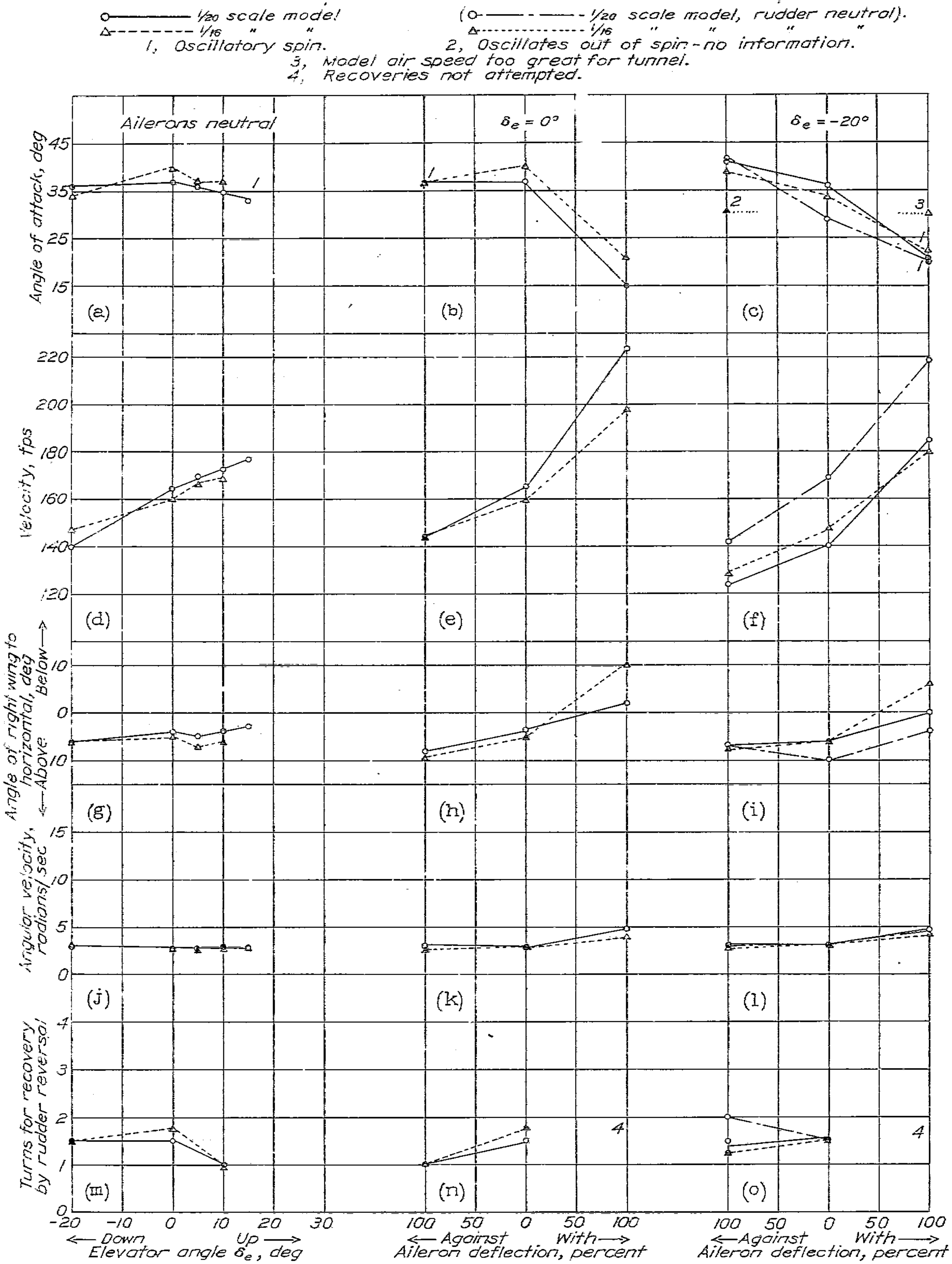


Figure 6.- Effect of scale on two models in the NACA 15-foot free-spinning wind tunnel. Modified load(I_Y and I_Z increased 30 percent I_Y); rudder 30° with spin; right spins.

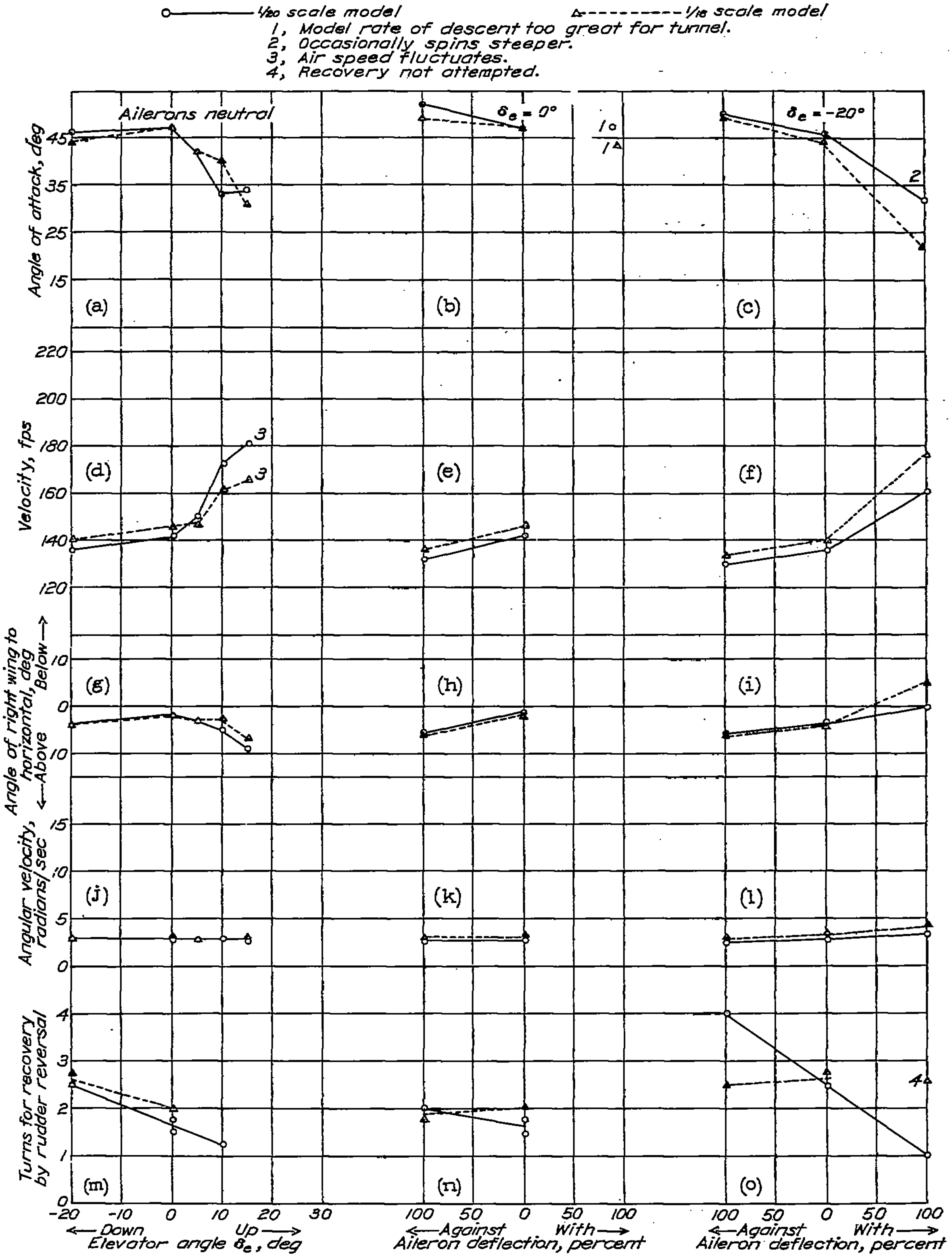


Figure 7.- Effect of scale on two models in the NACA 15-foot free-spinning wind tunnel. Modified load (I_Y and I_Z increased 30 percent I_Y); auxiliary fin 1 in place; rudder 30° with spin; right spins.

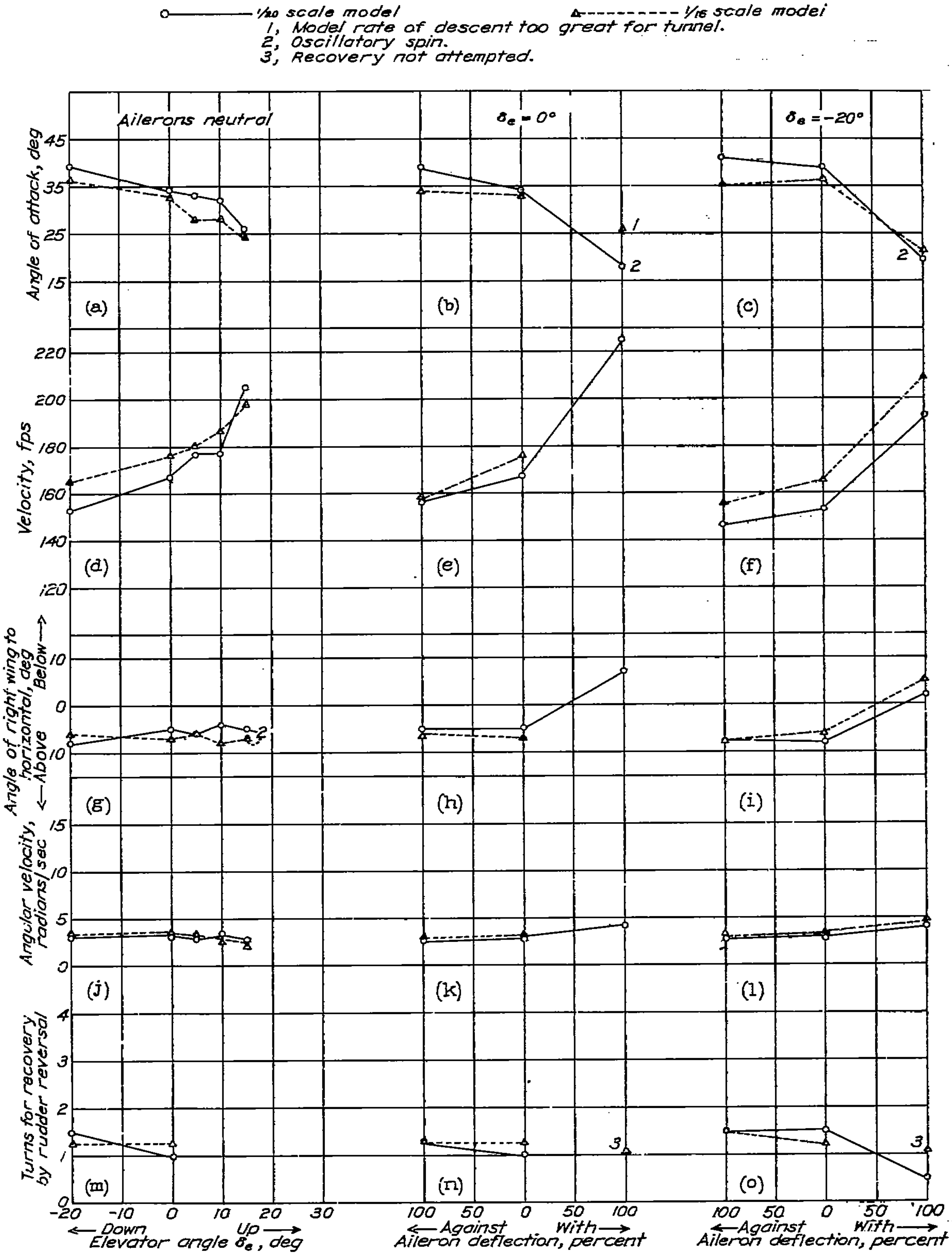


Figure 8.- Effect of scale on two models in the NACA 15-foot free-spinning wind tunnel. Modified load (I_Y and I_Z increased 30 percent I_Y); auxiliary fin 2 in place; rudder 30° with spin; right spins.