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THE EFFECT OF SPANWISE MASS DISTRIBUTION UPON THE SPIN CHARACTERISTICS OF AIRPLANES AS DETERMINED BY MODEL TESTS CONDUCTED IN THE FREE-SPINNING WIND TUNNEL

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THE EFFECT OF SPANWISE MASS DISTRIBUTION UPON THE SPIN CHARACTERISTICS OF AIRPLANES AS DETERMINED BY MODEL TESTS CONDUCTED IN THE FREE-SPINNING WIND TUNNEL

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SUMMARY

Previous work has shown certain characteristic differences in the spins of single-engine and multiengine aircraft. The multiengine aircraft have almost invariably spun at low angles of attack with high rates of descent and large load factors and the elevator has been the most effective control for recovery. The spins of the single-engine aircraft, however, have varied through a wide range of angles of attack and the rudder has been the most effective control for recovery.

This investigation was intended to determine whether the difference in the spanwise loading of the two types of aircraft was responsible for the differences in spin characteristics, particularly as regards the angle of attack. Six models, five of single-engine and one of a multiengine aircraft, were tested. The spanwise loadings of the single-engine models were increased greatly and the spanwise loading of the multiengine model was decreased.

The model test results indicated that the spanwise loading does not control the angle of attack of an airplane in a spin, but that it does influence the relative effectiveness of the ailerons and the elevator on recovery.

INTRODUCTION

In reference 1, certain characteristic differences between the spins of single-engine and multiengine aircraft, as indicated by model tests in the free-spinning wind tunnel, have been presented. For models of multiengine aircraft, the spins have almost invariably been at low angles of attack with high rates of descent. The elevator has been the most effective control for recovery. For models of single-engine aircraft, however, the spins obtained have covered a wide range varying from steep spins with high rates of descent to flat spins with low rates of descent. The rudder has been the most effective control for recovery.

Reference 1 suggested the differences in load distribution between the two types of aircraft as a possible reason for the different spinning characteristics. The loading of multiengine aircraft differs from that of single-engine aircraft in that a greater proportion of the load is carried in the wing and a smaller proportion is carried in the fuselage. Reference 2 indicated that the type of loading is important in determining the relative effectiveness of the elevator and rudder controls for recovery.

The object of the present investigation was to establish the importance of spanwise loading in determining the differences between the spins of the two types of aircraft. The variation of the angle of attack with the loading was considered of especial importance because the attitude in the spin determines the load factor, which may be critical for large airplanes. The investigation consisted of tests of five models representative of single-engine aircraft and one model of a multiengine aircraft. The spanwise loadings of the single-engine models were increased to exceed a value representative of multiengine aircraft; while the spanwise loading of the multiengine model was decreased in an attempt to reach a value representative of single-engine aircraft. If the spanwise loading were the predominating factor, the spinning characteristics would presumably change as the loading was varied.

MODELS AND TESTS

Six models, five of single-engine and one of a multiengine aircraft, were used in the investigation. Photographs of the models are shown in figures 1 to 6. One basis used in selecting the single-engine models was to cover a wide range of aerodynamic characteristics, such as wing and tail arrangement, and tail-damping power factors as defined in reference 3. Another basis of selec-

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tion was that the normal spins be fairly flat so that a steepening due to change in load distribution could be detected. The dimensional characteristics of the six models are compared in table I.

For the investigation of the single-engine models, the proportion of the load carried in the wings was increased in several steps until the value of $\frac{k_X^2 - k_Y^2}{b^2}$ (where b is the span, k_X the radius of gyration about the X axis, and k_Y the radius of gyration about the Y axis) became greater than 59×10^{-4}, which was given in reference 1 as an average value for multiengine aircraft. The term $\frac{k_X^2 - k_Y^2}{b^2}$, which is generally called the inertia yawing-moment parameter and which, for convenience, will be abbreviated as IYMP, determines the inertia yawing moment for a given attitude and rate of rotation.

The changes were obtained by adding ballast weights to the wings of the models, thereby increasing k_X. The increase in mass caused by adding the wing weights was less than 10 percent of the total mass of the model in every case and was neglected in appraising the data. This procedure did not given typical multiengine values of either the inertia rolling-moment parameter $\frac{k_Y^2 - k_Z^2}{b^2}$ or the inertia pitching-moment parameter $\frac{k_Z^2 - k_X^2}{b^2}$ (k_Z is the radius of gyration about the Z axis). The value of the inertia rolling-moment parameter was greater negatively and the value of the inertia pitching-moment parameter was greater positively at the extreme loading conditions than typical multiengine values.

For the multiengine model, the endeavor was made to obtain a typical single-engine value of the IYMP. Reference 1 gives this value as -78×10^{-4}. As a first step, the loading along the wings was decreased by removing the nacelle ballast weights and installing them in the fuselage. It was necessary to construct a false nose on the model to house these weights, but the aerodynamic effect of the housing was believed to be slight. As a further decrease in the spanwise loading was impracticable, weight was added along the fuselage, thereby increasing k_Y until the desired value of the IYMP was obtained.

The values of the parameters of the models for the conditions tested are listed in table II.

All the models had been previously tested extensively. Inasmuch as increases in weight may have resulted in the course of early repairs, the actual conditions tested as the normal loadings were probably slightly different from those listed in the tables. As the subject tests were intended to show the effects of large variations in spanwise mass distribution, the differences were considered unimportant.

The aerodynamic effect of engine nacelles on the spinning characteristics was evaluated by removing the nacelles from the multiengine model and installing them on a single-engine model.

The models were tested in the NACA 15-foot free-spinning wind tunnel of the Langley Memorial Aeronautical Laboratory. The wind tunnel and the testing technique are described in reference 4. Complete measurements were made of only the steady-spin characteristics of the models. Reference 2 deals with the effects of load distribution on recovery characteristics.

RESULTS

The results of the investigation are given on charts 1 to 6. The steady-spin parameters presented on the charts were determine by the methods described in reference 4 and have been converted to corresponding full-scale values.

The following symbols are used:

α acute angle between thrust axis and vertical (approximately equal to angle of attack)

ϕ angle between span axis and horizontal, considered positive when the right wing is down

V true rate of descent, feet per second

Ω angular velocity about spin axis, radians per second

All these quantities occur in the expressions for the inertia moments acting during a spin. The load factor

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normal to the airplane thrust axis was computed as $1/\sin\alpha$ on the assumptions that the resultant force in a spin is normal to the thrust axis and that the vertical component of the resultant force is equal to the weight of the airplane. Where recovery data are presented, recoveries were generally attempted by full rudder reversal; although in some instances, which are noted, both the rudder and the elevator were reversed simultaneously. All data are for right-hand spins. "Ailerons with the spin" therefore means right aileron up and left aileron down.

The test results presented on the charts are believed to be the true values within the following limits:

α . . . . $\pm 3^\circ$

ϕ . . . . $\pm 1^\circ$

V . . . . ± 2 percent

Ω . . . . ± 2 percent

Turns for recovery . . . . $\pm 1/4$ turn

The preceding limits may have been exceeded for certain spins where it was difficult to handle the model in the tunnel, owing to the high airspeed or to the wandering or oscillatory nature of the spin.

For model I (table II, chart 1) in the normal loading condition the IYMP equalled -97×10^{-4} and all spins with the ailerons either neutral or against the spin were fairly flat (α from 53° to 62°); while the aileron-with spins appeared to be quite steep. There appeared to be very little difference in attitude between the spins with the elevator down or up.

When the spanwise mass was increased until the value of the IYMP was -24×10^{-4} (condition I), all spins with the elevator neutral or down were at an angle of attack of approximately 43°. The spins obtained with the elevator up were still flat with the possible exception of the aileron-with spin, which was too wandering to test completely.

When the spanwise mass was further increased until the value of the IYMP was 62×10^{-4}, the aileron effect definitely reversed, as the aileron-with spins were now flat (α from 51° to 63°) and elevator-up was the only control setting for which the model would spin when the ailerons were against the spin. The model also would not spin when the silerons were neutral and the elevator was down. In the subsequent discussion this result shall be considered as a reversal of the elevator effect for single-engine airplanes. Increasing the spanwise mass still further to a value of 90×10^{-4} for the IYMP had no additional effect. The aileron-with spins were flatter than corresponding spins usually obtained for multiengine aircraft, and the load factors obtained were therefore smaller.

Only a few recoveries were obtained for this model. It appears, however, that recovery either by rudder reversal alone or by simultaneous rudder and elevator reversal from the aileron-with, elevator-up spin was retarded as the spanwise mass was increased.

The results obtained with model II (table II, chart 2) were similar to those obtained with model I; although the aileron and elevator effects did not reverse until more extreme values of the IYMP were obtained. The aileron effect did not reverse completely until the value of the IYMP was 97×10^{-4} and the elevator effect did not reverse completely until the parameter value was 135×10^{-4}. All spins for which complete data were obtained were flatter than typical multiengine spins and gave smaller load factors.

The recoveries obtained by rudder reversal alone for all aileron-neutral, elevator-up spins were practically the same for all loading conditions tested. Too few recoveries were obtained from the other conditions to show any definite trend.

Model III (table II, chart 3) was more heavily loaded along the wing in its normal loading condition than any of the other single-engine models tested, and the value of the IYMP was -15×10^{-4}. This model had the aileron effect typical of multiengine aircraft; that is, with ailerons set against the spin, the model would not spin when the elevator was neutral or down and the vertical velocity of the model was too high to test when the elevator was up, ailerons against the spin; whereas, when the ailerons were neutral or with the spin, the spins were at moderate angles of attack (α from 40° to 45°). Except when the ailerons were against the spin, the elevator effect was slight.

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As a first step in an endeavor to obtain the normal single-engine spin characteristics, the spanwise mass was decreased as much as possible. The maximum negative value of the IYMP obtainable was -40×10^{-4}. At this value of the parameter, control effects were not definite, as all aileron-against spins and all elevator-up spins were too oscillatory to test. The spins for which data were obtained were quite steep (α from 32° to 38°).

When the spanwise mass distribution was increased until the IYMP was 8×10^{-4}, the spin characteristics of the model were not changed appreciably from the characteristics obtained with the model in its normal loading condition, except that the model would not spin for this loading when the ailerons were neutral and the elevator was down. Further increases in the spanwise mass distribution to parameter values of 62×10^{-4} and 90×10^{-4} had little further effect. Not enough recoveries were obtained for this model to show any trends in recovery characteristics.

The results obtained with model IV (table II, chart 4) were similar to those obtained with model I. The aileron effect was reversed at a value of the IYMP of -2×10^{-4}. The elevator effect was reversed at a parameter value of 62×10^{-4}.

The aerodynamic effect of nacelles on the wings was determined on this model by testing the model first with the nacelles of the multiengine model installed and then with the nacelles removed but with equivalent weights installed. The effect was found to be small, the nacelles merely tending to reduce the rates of descent somewhat. For this model, also, too few recovery tests were made to note any trend in the recovery characteristics.

The results obtained for model V (table II, chart 5) also resembled the results obtained for model I. The aileron effect was reversed at a value of the IYMP of 35×10^{-4}, and the elevator effect was reversed at a parameter value of 120×10^{-4}. The spins for which complete measurements were obtained for the extreme loading conditions (IYMP = 120×10^{-4} and 215×10^{-4}) were flatter than typical multiengine spins. Increasing the spanwise mass retarded the recoveries by rudder reversal alone from the aileron-neutral, elevator-up condition. The other recoveries obtained did not show much, except that, at the extreme wing-heavy loading conditions, recovery from the aileron-with, elevator-up spins was impossible by either rudder reversal alone or simultaneous rudder and elevator reversal.

Model VI (table II, chart 6) represented a multiengine aircraft. For the normal loading condition the value of the IYMP was 76×10^{-4} and the model spun only when the elevator was full up and the ailerons were neutral or with the spin. The aileron-with spin was rather steep ($\alpha = 36^{\circ}$) and the rate of descent was quite high (207 fps). The aileron-neutral spin appeared to be steeper and the model descended with a vertical velocity too high to test.

As the first step in the attempt to simulate single-engine load distribution the spanwise mass was decreased as much as was practicable, and a value of -11×10^{-4} for the IYMP was obtained. For this condition the model spun for all the aileron-with settings and also when the ailerons were neutral and the elevator was up or neutral. The aileron-with, elevator-up spin was too oscillatory to test. The angles of attack varied from 31° to 33° for the spins obtained.

As it was not practicable to remove more mass from the wings of the model, mass was added along the fuselage in an endeavor to obtain a high negative value of the IYMP. When the value of the parameter was -61×10^{-4} the model spun for all control settings except when the ailerons were against the spin and the elevator was down. The angles of attack of the spins for which complete measurements were obtained varied from 28° to 34°.

The aerodynamic effect of the nacelles was determined by removing them from the model and installing equivalent weights in their places. The most noticeable effect was that, without the nacelles, the aileron-with spins were from 8° to 16° flatter than they were with the nacelles installed. The value of α varied from 28° to 46° for the spins obtained.

When the nacelles were removed and no equivalent weights installed, the value of the IYMP was -91×10^{-4}, and the model spun for all combinations of aileron-elevator settings. The aileron-against spins were slightly steeper with higher rates of descent than the aileron-with spins when the elevator was up or neutral; whereas the opposite was true when the elevator was down. The elevator position affected only the wing inclination ϕ. All spins were steep, the angle α varying from 24° to 32° for this condition.

DISCUSSION

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It has been shown in reference 1 that multiengine aircraft spin steeply and descend with vertical velocities which may be as high as 340 feet per second or even higher. The load factors may be as large as 2.7 or even larger. Movement of the elevator down and of ailerons against the spin is especially effective for recovery. Single-engine airplane spins may be either steep or flat with either high or low rates of descent and either high or low load factors. The rudder is the most effective control for recovery, and the ailerons should be moved with the spin to expedite recovery further.

In their normal loading conditions, the five single-engine models tested had, for the control settings for which complete data were obtained, angles of attack varying from 80° to 28° and rates of descent varying from 110 to more than 272 feet per second. The load factors varied from 1.0 to 2.1. It should be realized that, because of scale effect, the range of load factors experienced by the full-scale airplane may differ from the range obtained in the model tests. At the extreme spanwise loading conditions the angles of attack varied from 64° to 35°, the rates of descent varied from 150 to more than 272 feet per second, and the load factors varied from 1.1 to 1.7. For these extreme loadings, the steep spins with the high rates of descent were in all cases obtained with aileron-against settings. The aileron-with spins obtained were, in general, at higher angles of attack with lower rates of descent and smaller load factors than typical multi-engine spins. It appears, therefore, that the spanwise mass distribution does not determine the attitude of the spin for single-engine aircraft.

The control effects obtained for all single-engine models in their normal conditions, except model III, which was heavily loaded along the wings, were typical of single-engine aircraft. Aileron-with settings gave steeper spins with higher rates of descent than did aileron-against settings. Elevator-up settings usually gave steeper spins with higher rates of descent than did elevator-down settings; although in several instances this effect was negligible.

At the extreme spanwise-loading conditions, aileron-against and elevator-down settings tended to prevent spins, as is typical of multiengine airplanes. The aileron effect reversed at values of IYMP from -20×10^{-4} to 70×10^{-4} for two models and from -156×10^{-4} to 30×10^{-4} for the other three. The elevator effect reversed at values from -25×10^{-4} to 60×10^{-4} for three models, between a value of 35×10^{-4} and 120×10^{-4} for one model and between 97×10^{-4} and 135×10^{-4} for the other. A study of the charts shows that for the aileron-neutral, elevator-down spins, as the values of the IYMP were increased, there were only relatively small decreases in angles of attack and increases in airspeeds up to certain points. At these points sharp transitions occurred, as further increases in the IYMP led to conditions where the models would not spin.

Reference 2 gives more definite reversal regions for both the aileron and the elevator effect, but it must be remembered that recovery characteristics were considered in determining those regions; whereas only steady-spin characteristics were considered in the current tests. It it believed that, for loading conditions in which I_X is greater than I_Y, the angle of attack and airspeed may not be indicative of the effectiveness of the rudder in recovery, which probably accounts in part for the apparent discrepancies in the reversal regions found in reference 2 and in the present report.

The multiengine model in its normal loading condition spun at an angle of attack of 36° with a rate of descent of 207 feet per second and had a load factor of 1.7 for the one control setting for which results could be obtained. As the single-engine loading condition was approached, no tendency was observed for the spin to become flatter with lower rates of descent and smaller load factors. At the loading condition where the value of the IYMP was -91×10^{-4}, for example, the angles of attack of the spins varied from 32° to 24°, the rates of descent ranged from 211 to 250 feet per second, and the load factors varied from 1.9 to 2.5. In the normal loading condition the control effect was typical of multiengine aircraft, as the model would not spin for elevator-down and aileron-against settings. At the extreme loading condition with the spanwise mass decreased and the longitudinal mass increased, neither the aileron nor the elevator effect was definite.

The results of these tests show that the angles of attack and, hence, the load factors do not vary systematically with spanwise loading, indicating that the spanwise loading is not the sole factor determining the differences in the spins of the two types of aircraft. The control effects did, however, vary in a consistent manner as the spanwise loading was varied.

As previously mentioned, the values of the inertia rolling-moment parameters obtained for the single-engine models at the extreme loading conditions were greater negatively and the values of the inertia pitching-moment parameters were greater positively than typical multiengine values. The values of the inertia pitching-moment parameters remained constant at their normal single-engine values, as adding weight to the wings increased both k_Z and k_X by equal amounts. The persistent flat spins obtained may have been associated with one or both of these factors. Further research is in progress to isolate the effects of these factors.

In one loading condition the multiengine model had values of the inertia rolling- and pitching-moment parameters that were very close to typical single-engine values. This model had a twin tail and, consequently, an exceptionally high value for the tail-damping power factor. This condition may account for the steep spins that persisted throughout the loading conditions tested. If the value of the tail-damping power factor had not been so great, the inertia effects might have predominated over the aerodynamic effects and flatter spins, with typical single-engine spin characteristics, might have been obtained. The values of tail-damping power factors of several of the single-engine models tested were not greatly different from the values listed for several of the multiengine models of reference 1, although they were considerably lower than the values for the multiengine model tested herein.

CONCLUSIONS

The results of this series of tests lead to the following general conclusions:

1. The difference in the proportions of the loading carried in the wings for single-engine and multiengine

airplanes, as expressed by the inertia yawing-moment parameter, does not appear to be the factor controlling the angle of attack of an airplane in a spin.

2. The difference in spanwise loading appears to bear a consistent relation to the relative effectiveness of the ailerons and elevator on the recovery characteristics.

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REFERENCES

1. Seidman, Oscar, and Kamm, R. W.: Multiengine Airplane Spin Characteristics as Indicated by Model Tests in the Free-Spinning Wind Tunnel. NACA A.R.R., July 1942.

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

3. Seidman, Oscar, and Donlan, Charles J.: An Approximate Spin Design Criterion for Monoplanes. T.N. No. 711, NACA, 1939.

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

TABLE I

GENERAL COMPARISON OF FULL-SCALE DESIGN CHARACTERISTICS OF MODELS TESTED.

Model	Airplane	Type	Mass (slugs)	Wing area, S (sq ft)	c.g. in percent M.A.C.	Over-all length (ft)	Span (ft)	I_X (slug-ft^2)	I_Y (slug-ft^2)	I_Z (slug-ft^2)	Tail damping power factor (a)	Relative density (b)
I	SBN-1	Midwing monoplane; single engine; partial length rudder	184	258	24.3	27.83	39	3,223	5931	8,752	0.0000727	7.67
II	XF4F-3	Midwing monoplane; single engine; partial length rudder	181	260	23.84	26.92	38	2,878	5385	7,630	.0000727	7.72
III	XF4U-1	Low-wing monoplane; single engine; partial length rudder	267.5	314	24.9	31.91	41	7,400	8072	14,421	.0002720	8.75
IV	V-143 (long tail)	Low-wing monoplane; single engine; partial length rudder	135	187	26.2	28.80	33.5	1,648	2871	3,893	.0005240	9.05
V	XP-39	Low-wing monoplane; single engine; full-length rudder	181	213	26.4	29.72	34	2,420	5670	7,150	.0002200	10.60
VI	XF5F-1	Low-wing monoplane; two engine; twin tail; full-length rudders	268	303.5	23.2	28.91	42	10,787	7174	17,264	.0019730	8.83

[a]Calculated as outlined in reference 3.

[b]Calculated at sea level.

TABLE II

CONDITIONS TESTED WITH VARIOUS MODELS

[All changes, except where indicated, made by increasing mass along wing]

Condition	b/k_X	b/k_Y	b/k_Z	$\frac{k_X^2-k_Y^2}{b^2}$	$\frac{k_Y^2-k_Z^2}{b^2}$	$\frac{k_Z^2-k_X^2}{b^2}$
	Mass parameter					
Model I						
Normal loading	9.30		5.65	-97×10^{-4}	-101×10^{-4}	
I	7.30		5.10	-24	-173	198×10^{-4}
II	6.04	6.88	4.61	62	-260	
III	5.75		4.50	90	-288	
Model II						
Normal loading	9.54		5.85	-96×10^{-4}	-86×10^{-4}	
I	6.91		5.06	4	-186	182×10^{-4}
II	6.04	6.98	4.68	69	-251	
III	5.75		4.55	97	-279	
IV	5.41		4.37	135	-400	
Model III						
Normal loading	7.80		5.59	-15×10^{-4}	-141×10^{-4}	
[a]I	8.46		5.81	-40	-117	156×10^{-4}
II	7.30	7.46	5.40	8	-164	
III	6.44		5.01	62	-218	
IV	6.10		4.85	90	-246	
Model IV						
Normal loading	9.60		6.24	-81×10^{-4}	-67×10^{-4}	
I	7.30		5.46	-2	-146	148×10^{-4}
II	6.30	7.25	5.00	62	-211	
III	5.99		4.84	90	-238	
IV and IVa (effect of nacelles)	5.70		4.68	118	-265	
Model V						
Normal loading	9.30		5.41	-156×10^{-4}	-71×10^{-4}	226×10^{-4}
I	5.73	6.06	4.26	35	-262	
II	5.05		4.02	120	-346	
III	4.55		3.74	215	-441	
Model VI						
Normal loading	6.56	8.08	5.25	76×10^{-4}	-214×10^{-4}	137×10^{-4}
[a]I	8.45	8.13	6.00	-11	-126	137
[b]II	8.45	7.05	5.54	-61	-126	186
[c]III	8.45	7.05	5.54	-61	-126	186
[d]IV	9.51	7.05	5.80	-91	-96	187

[a]Mass along wing decreased.
[b]Condition I and mass along fuselage increased.
[c]Starting with condition II, nacelles removed and equivalent weight installed.
[d]Starting with condition III, equivalent weight of nacelles removed.

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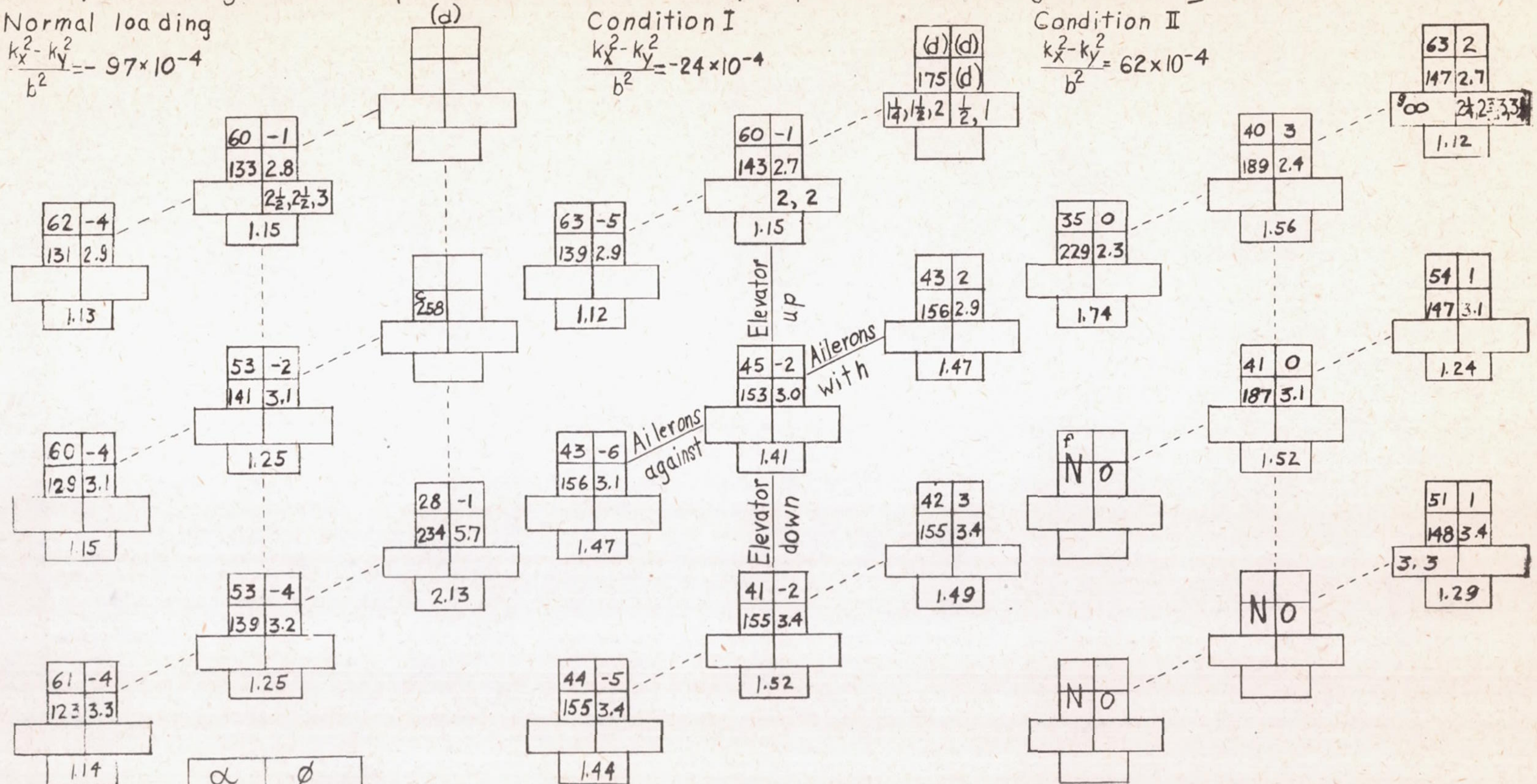
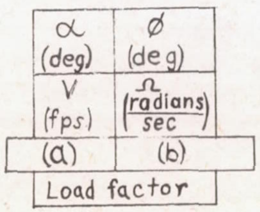
Chart 1.- SPIN CHARACTERISTICS OF MODEL I

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt]





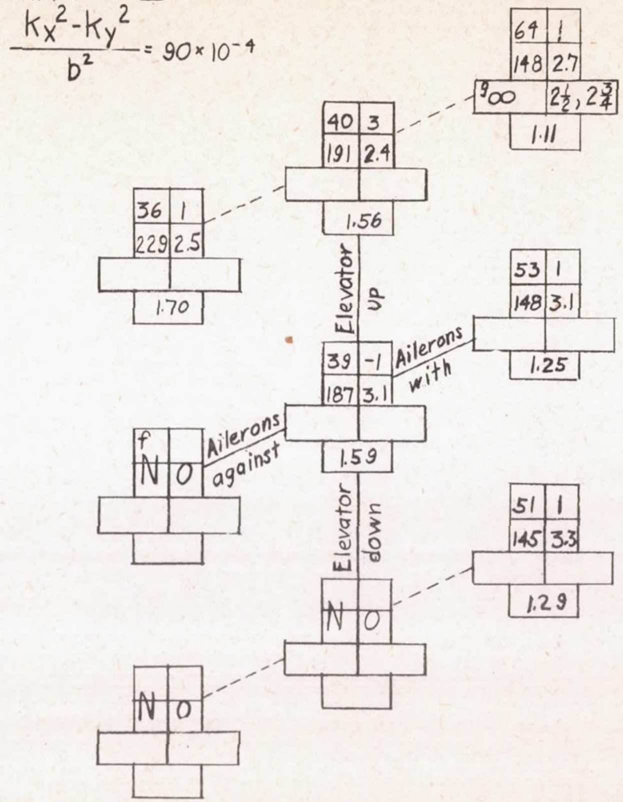
[a] Turns for recovery; recovery attempted by full rapid rudder reversal.
[b] Turns for recovery; recovery attempted by simultaneous reversal of rudder and elevator.
[c] High vertical velocity in excess of value noted.
[d] Wandering spin.
[e] Oscillatory spin.
[f] No, indicates model would not spin. [g] ∞, indicates model would not recover.

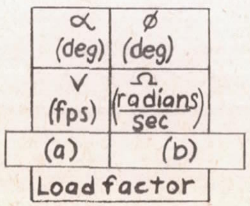
Chart 1.- Continued. SPIN CHARACTERISTICS OF MODEL I.

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]

Condition III

$$\frac{k_X^2 - k_Y^2}{b^2} = 90 \times 10^{-4}$$





a Turns for recovery; recovery attempted by full rapid rudder reversal.
b Turns for recovery; recovery attempted by simultaneous reversal of rudder and elevator.
c High vertical velocity in excess of value noted.
d Wandering spin.
e Oscillatory spin.
f No, indicates model would not spin.
g ∞, indicates model would not recover.

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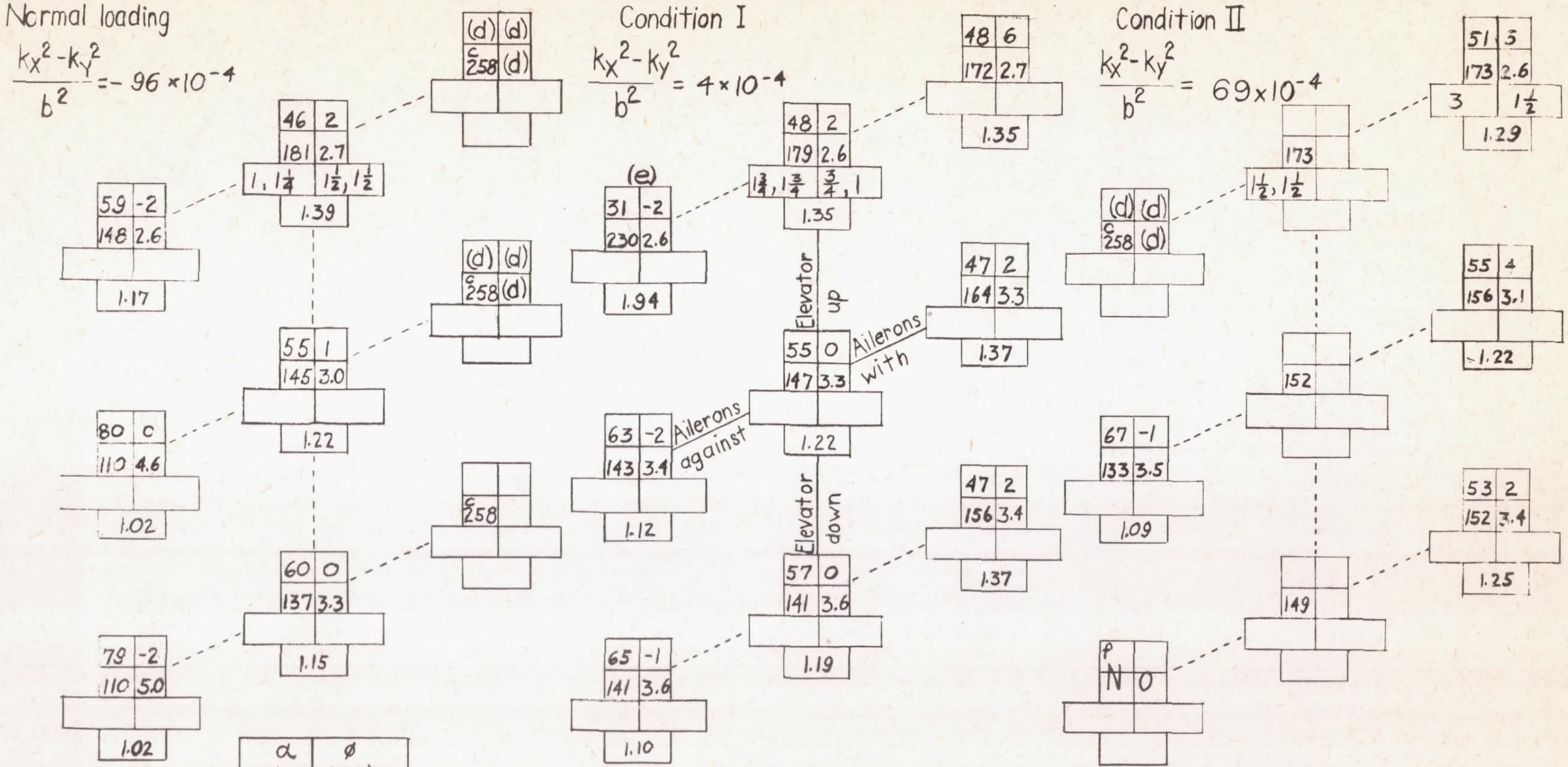
Chart 2.- SPIN CHARACTERISTICS OF MODEL II

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]



α (deg)	ϕ (deg)
V (fps)	Ω (radians/sec)
(a)	(b)
Load factor	

[a] Turns for recovery; recovery attempted by full rapid rudder reversal.
[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.
[c] High vertical velocity in excess of value noted.
[d] Wandering spin.
[e] Oscillatory spin.
[f] No, indicates model would not spin.
[g] ∞, indicates model would not recover.

Chart 2

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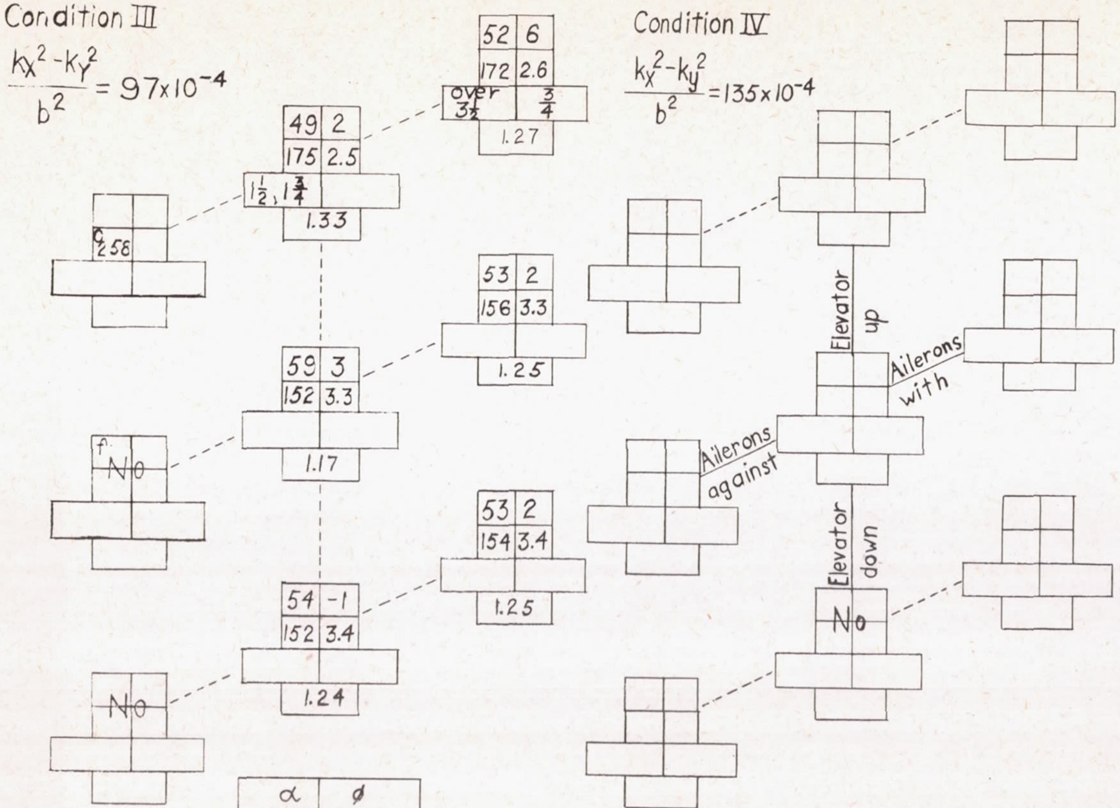
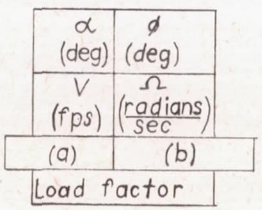
Chart 2.-Continued

SPIN CHARACTERISTICS OF MODEL II

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]



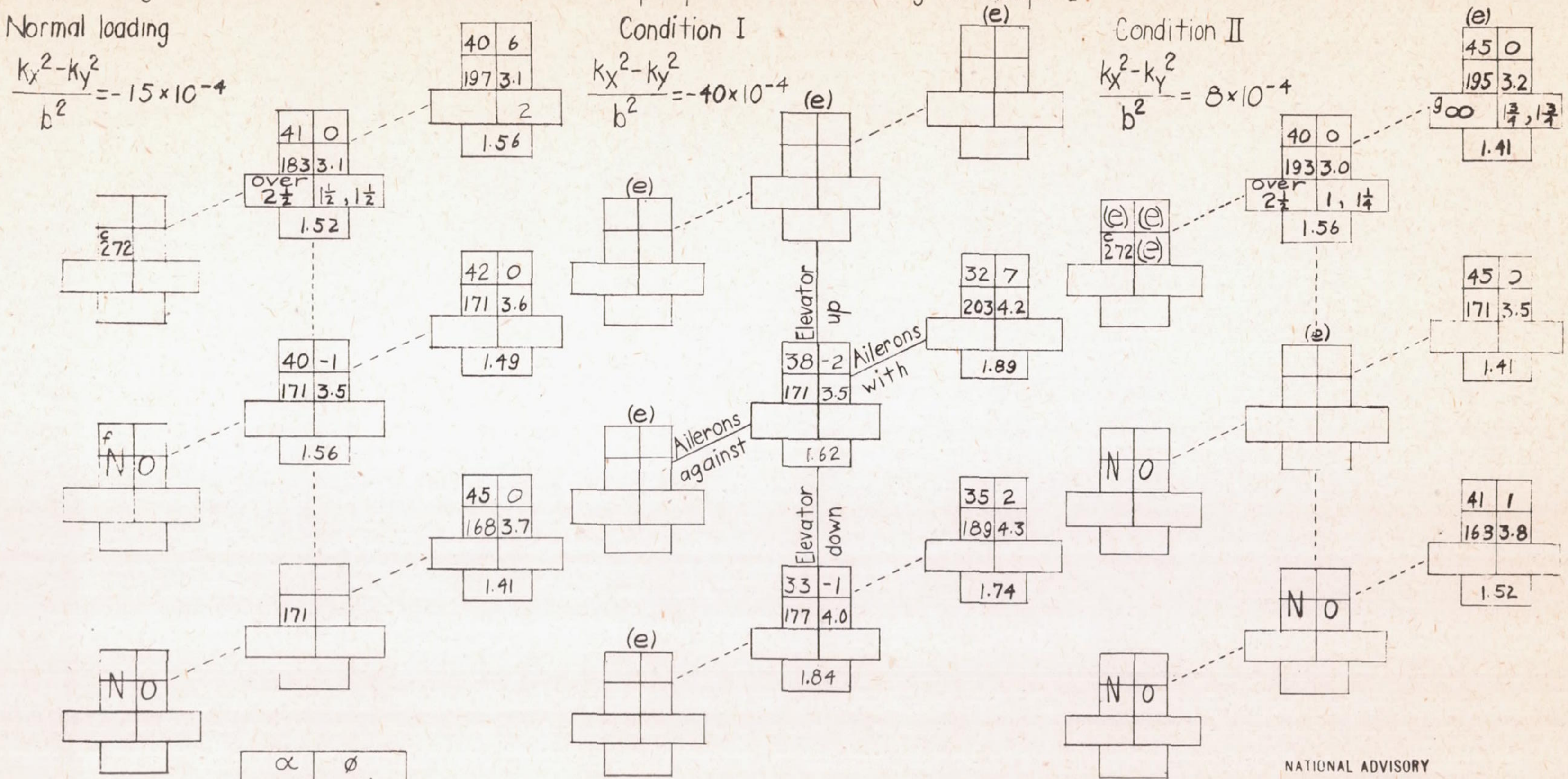


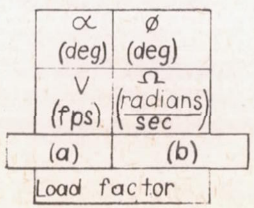
[a] Turns for recovery; recovery attempted by full rapid rudder reversal.
[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.
[c] High vertical velocity in excess of value noted.
[d] Wandering spin.
[e] Oscillatory spin.
[f] No. indicates model would not spin
[g] ∞, indicates model would not recover

Chart 2 (C'td.)

Chart 3.- SPIN CHARACTERISTICS OF MODEL III

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]





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[a] Turns for recovery; recovery attempted by full rapid rudder reversal.
[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.
[c] High vertical velocity in excess of value noted.
[d] Wandering spin.
[e] Oscillatory spin.
[f] No, indicates model would not spin.
[g] ∞, indicates model would not recover.

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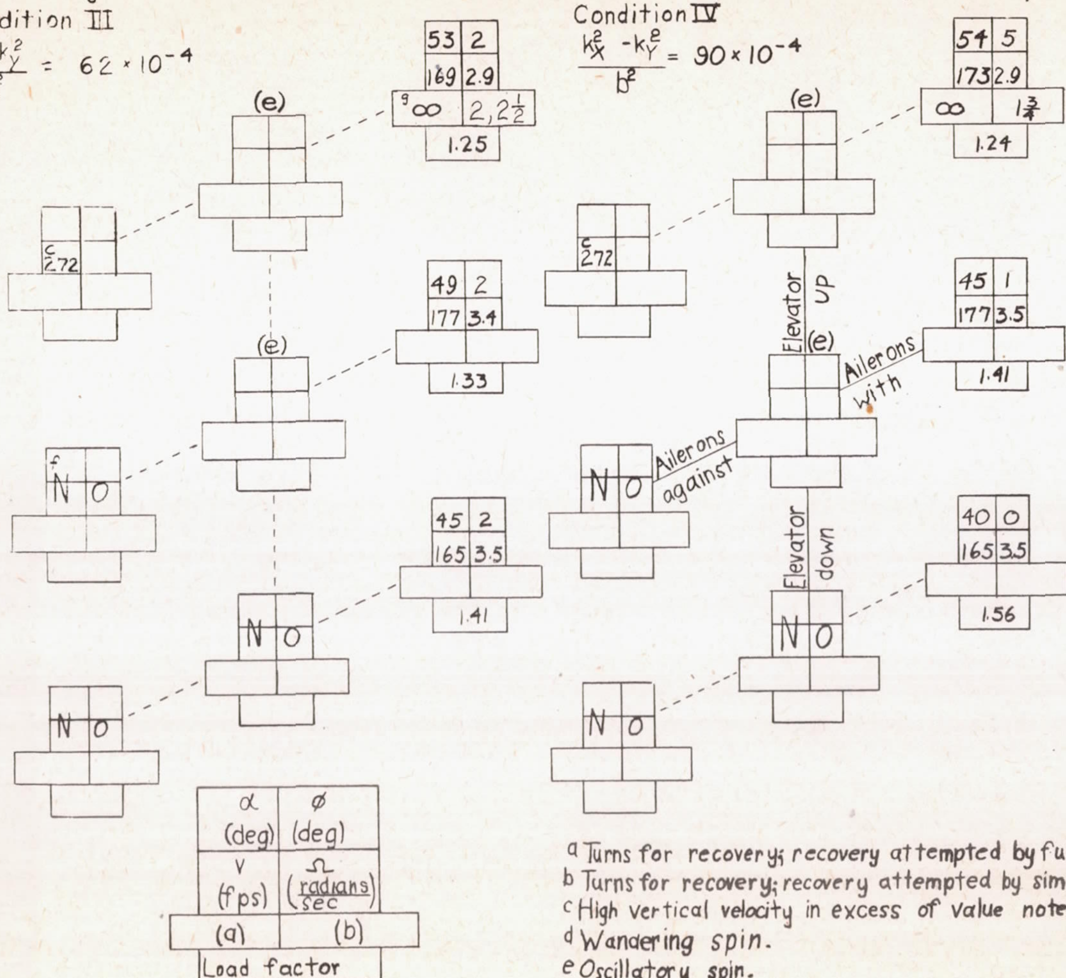
Chart 3.-Continued. SPIN CHARACTERISTICS OF MODEL III

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]

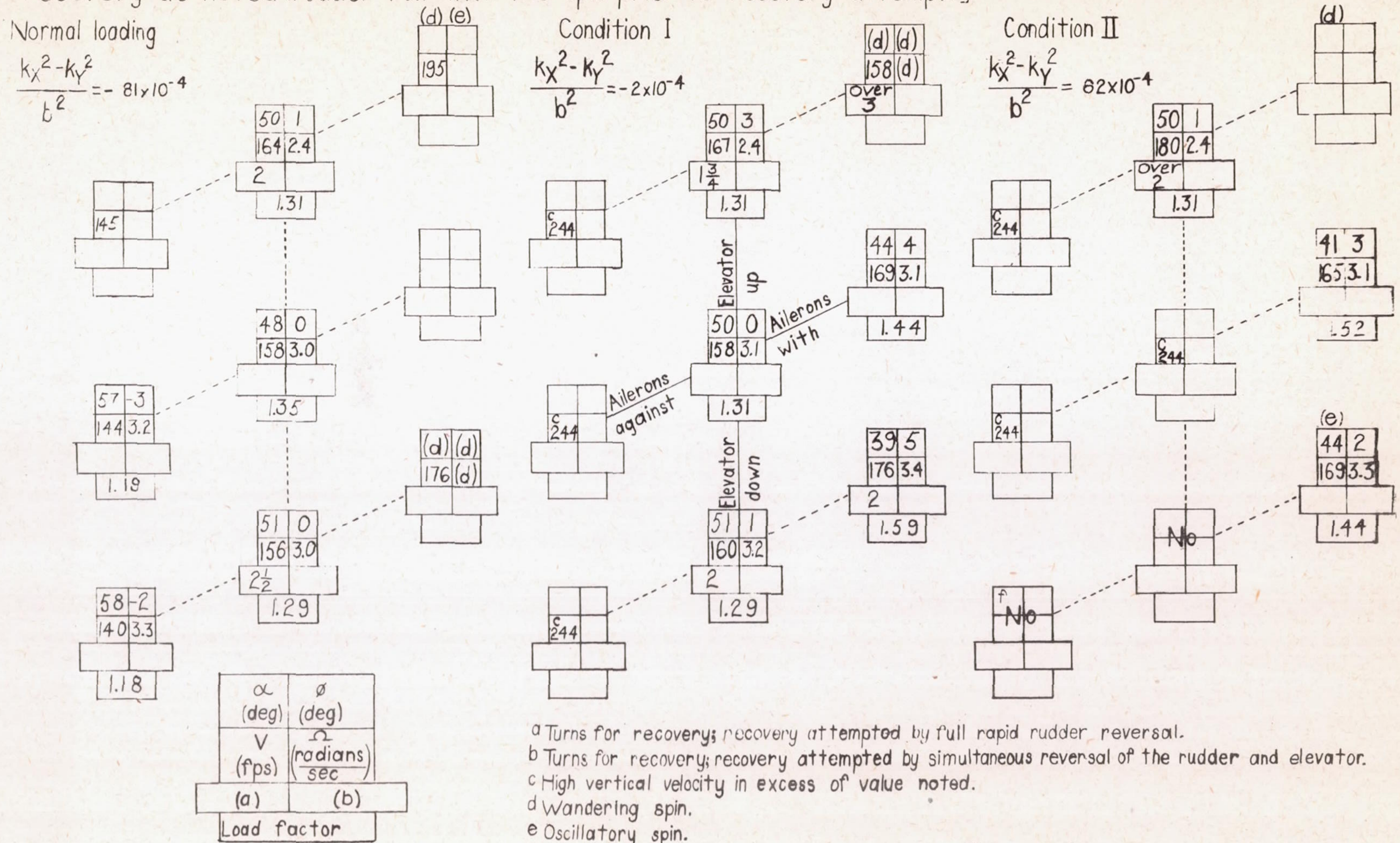


[a] Turns for recovery; recovery attempted by full rapid rudder reversal.
[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.
[c] High vertical velocity in excess of value noted.
[d] Wandering spin.
[e] Oscillatory spin.
[f] No indicates model would not spin. [g] ∞, indicates model would not recover.

Chart 3 (C'td.)

Chart 4.- SPIN CHARACTERISTICS OF MODEL IV

Effect of mass variations: loading as indicated; cockpit closed; landing gear retracted; flap setting neutral: recovery as noted (rudder full with the spin prior to recovery attempt)]



a Turns for recovery; recovery attempted by full rapid rudder reversal.

b Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.

c High vertical velocity in excess of value noted.

d Wandering spin.

e Oscillatory spin.

f No. indicates model would not spin. g ∞, indicates model would not recover.

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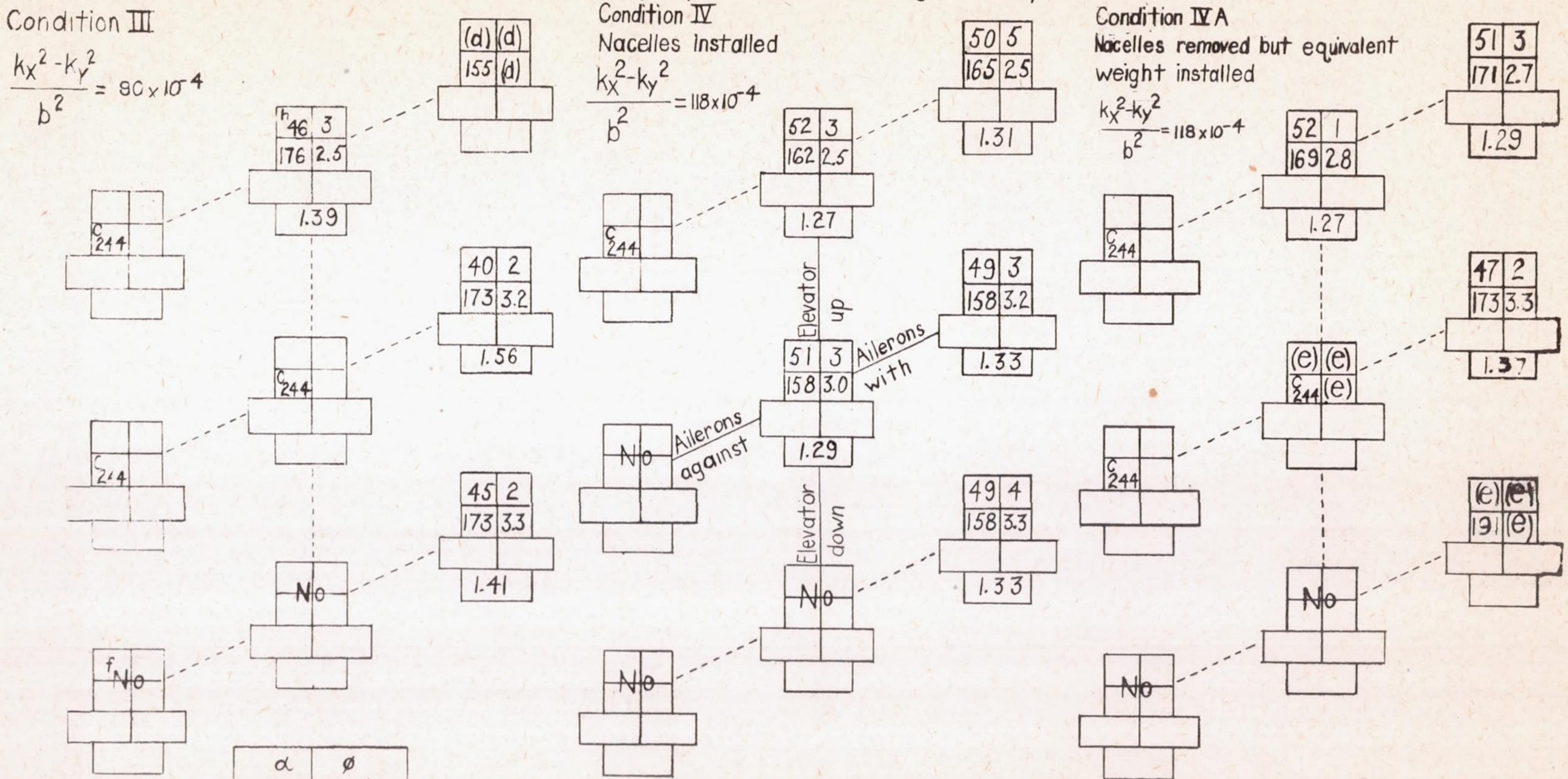
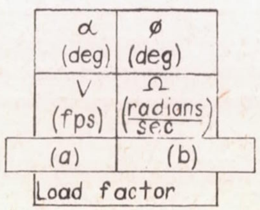
Chart 4-Continued.

SPIN CHARACTERISTICS OF MODEL IV

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]





[a] Turns for recovery; recovery attempted by full rapid rudder reversal.

[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.

[c] High vertical velocity in excess of value noted.

[d] Wandering spin.

[e] Oscillatory spin.

[f] No, indicates model would not spin.

[h] α varied from 38° at the beginning of the spin to 49° at the end of the recorded observations.

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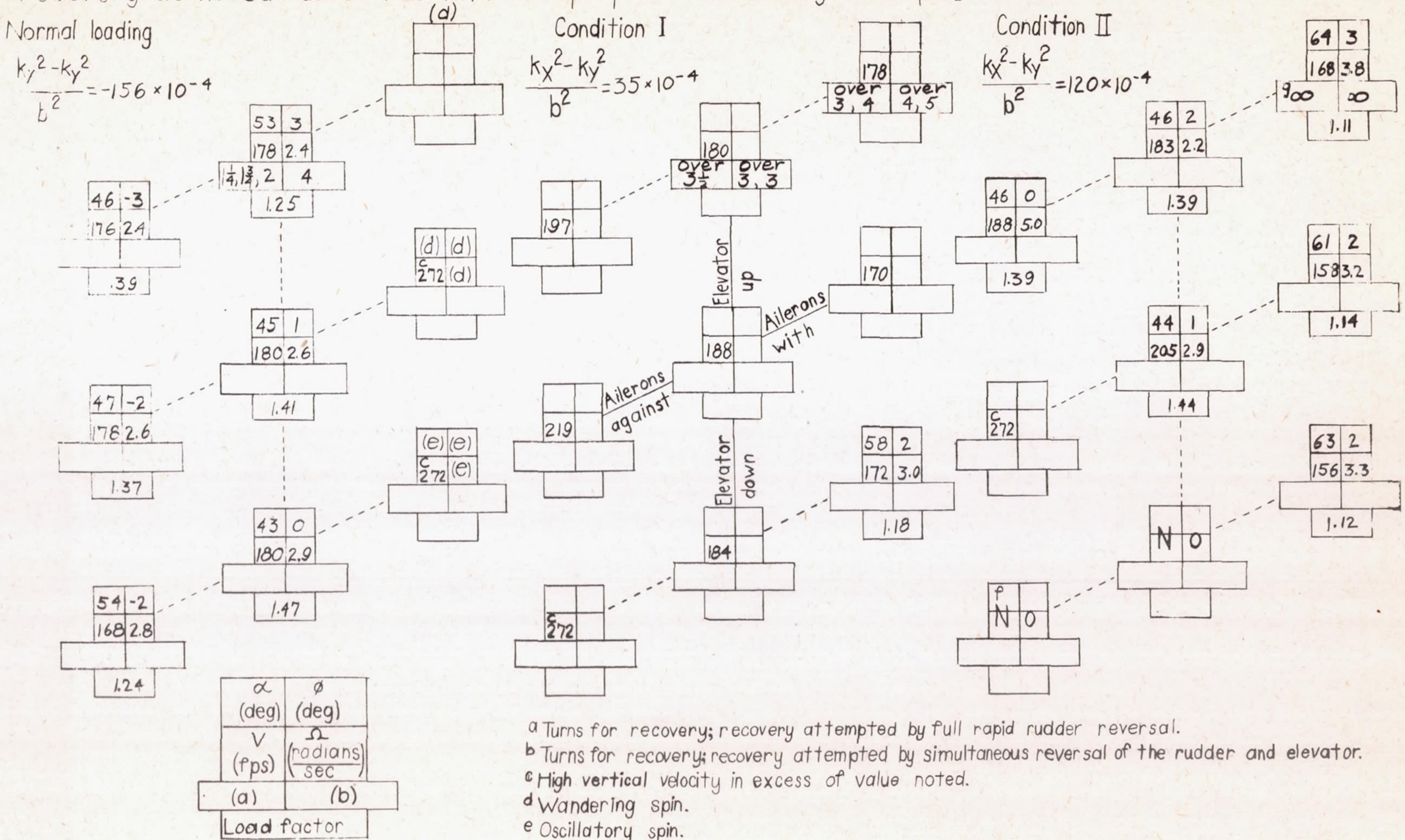
Chart 5.- SPIN CHARACTERISTICS OF MODEL V

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]



[a] Turns for recovery; recovery attempted by full rapid rudder reversal.

[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.

[c] High vertical velocity in excess of value noted.

[d] Wandering spin.

[e] Oscillatory spin.

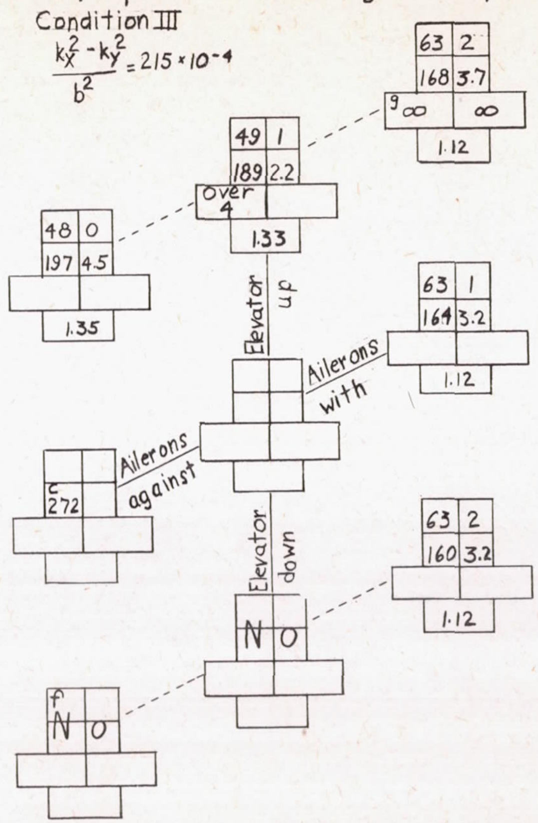
[f] No, indicates model would not spin.

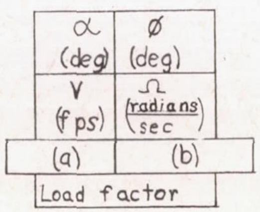
[g] ∞, indicates model would not recover.

Chart 5

Chart 5.- Continued. SPIN CHARACTERISTICS OF MODEL V

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]

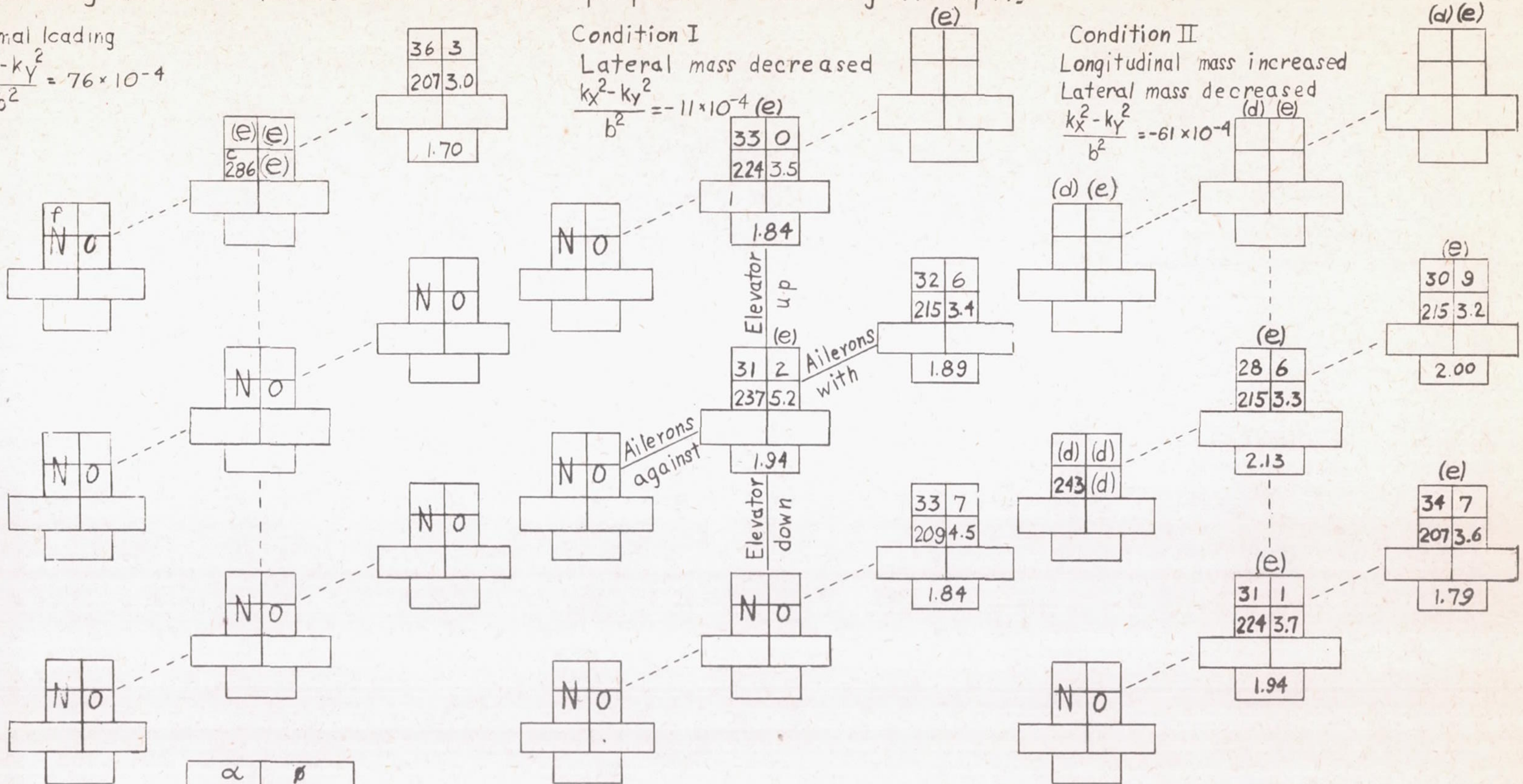


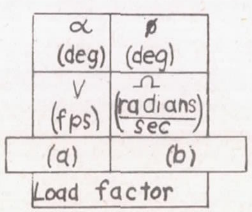


[a] Turns for recovery; recovery attempted by full rapid rudder reversal.
[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.
[c] High vertical velocity in excess of value noted.
[d] Wandering spin.
[e] Oscillatory spin.
[f] No, indicates model would not spin. [g] ∞, indicates model would not recover.

Chart 6.- SPIN CHARACTERISTICS OF MODEL VI

[Effect of mass variations; loading as indicated; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]





[a] Turns for recovery; recovery attempted by full rapid rudder reversal.
[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.
[c] High vertical velocity in excess of value noted.
[d] Wandering spin.
[e] Oscillatory spin.
[f] No, indicates model would not spin. [g] ∞, indicates model would not recover.

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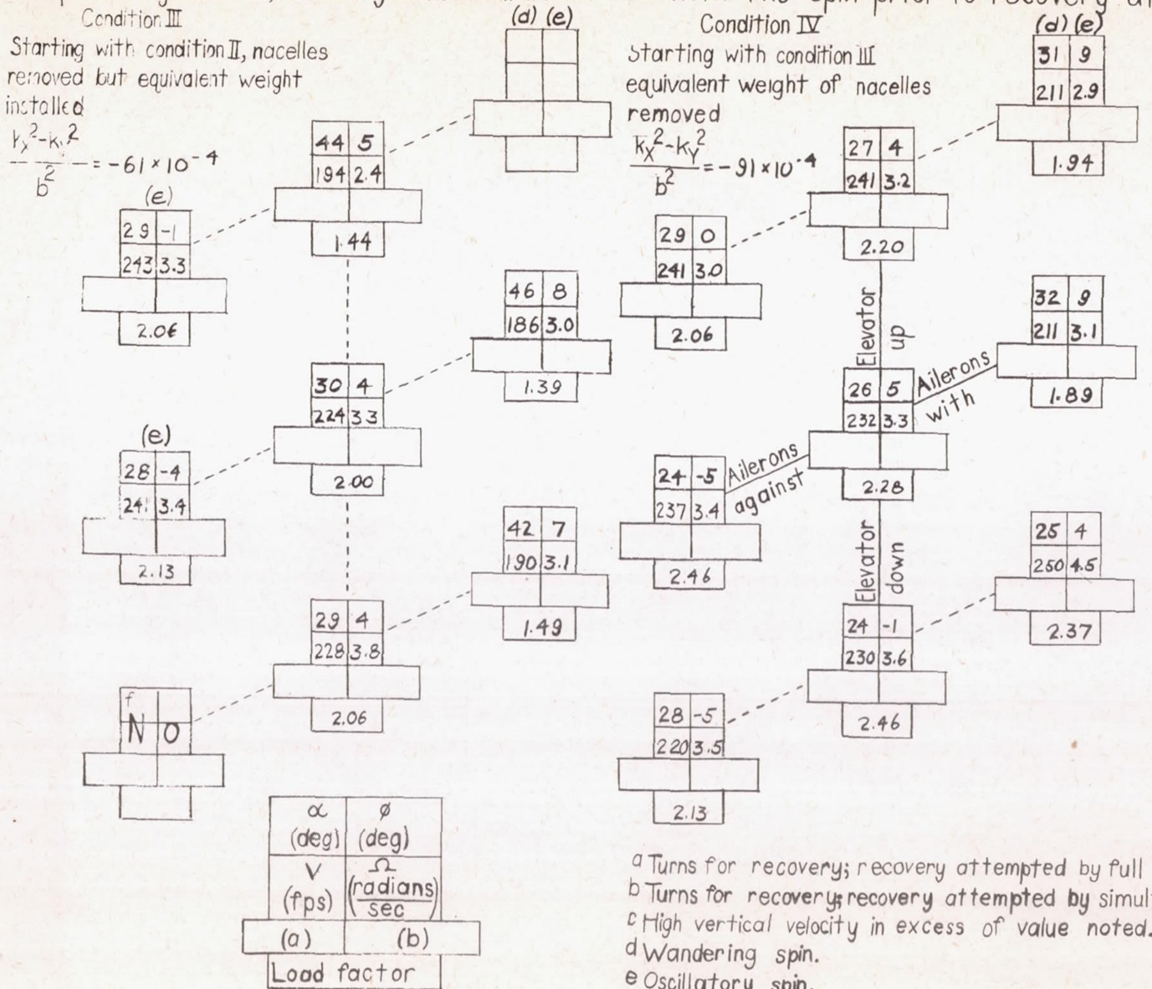
Chart 6.- Continued. SPIN CHARACTERISTICS OF MODEL VI

Aerodynamic effect of nacelles; loading, spanwise mass decreased; cockpit closed; landing gear retracted; flap setting neutral; recovery as noted (rudder full with the spin prior to recovery attempt)]



[a] Turns for recovery; recovery attempted by full rapid rudder reversal.

[b] Turns for recovery; recovery attempted by simultaneous reversal of the rudder and elevator.

[c] High vertical velocity in excess of value noted.

[d] Wandering spin.

[e] Oscillatory spin.

[f] No. indicates model would not spin.

[g] ∞, indicates model would not recover.

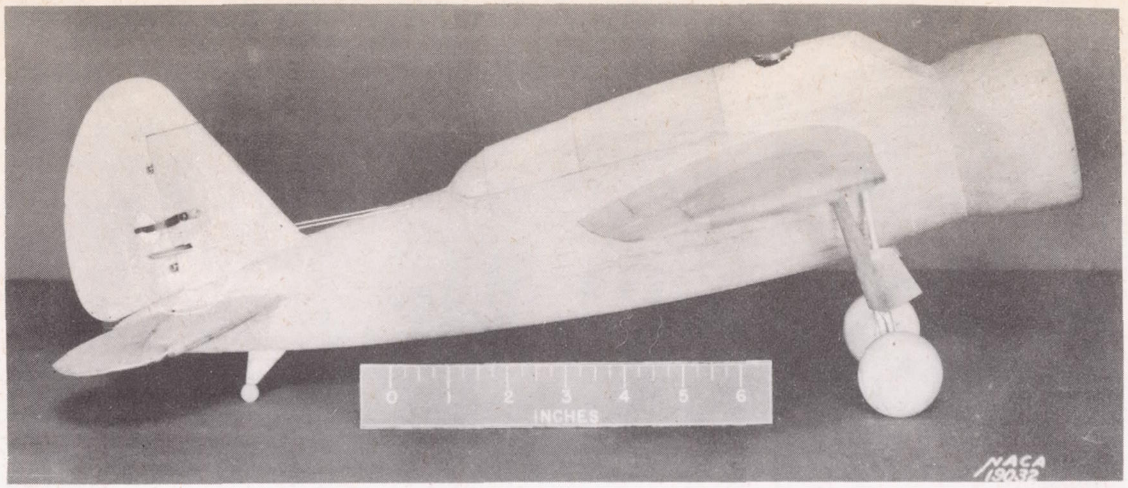


Figure 1.- Model I. A 1/18-scale model of the Naval Aircraft Factory SBN-1 airplane.

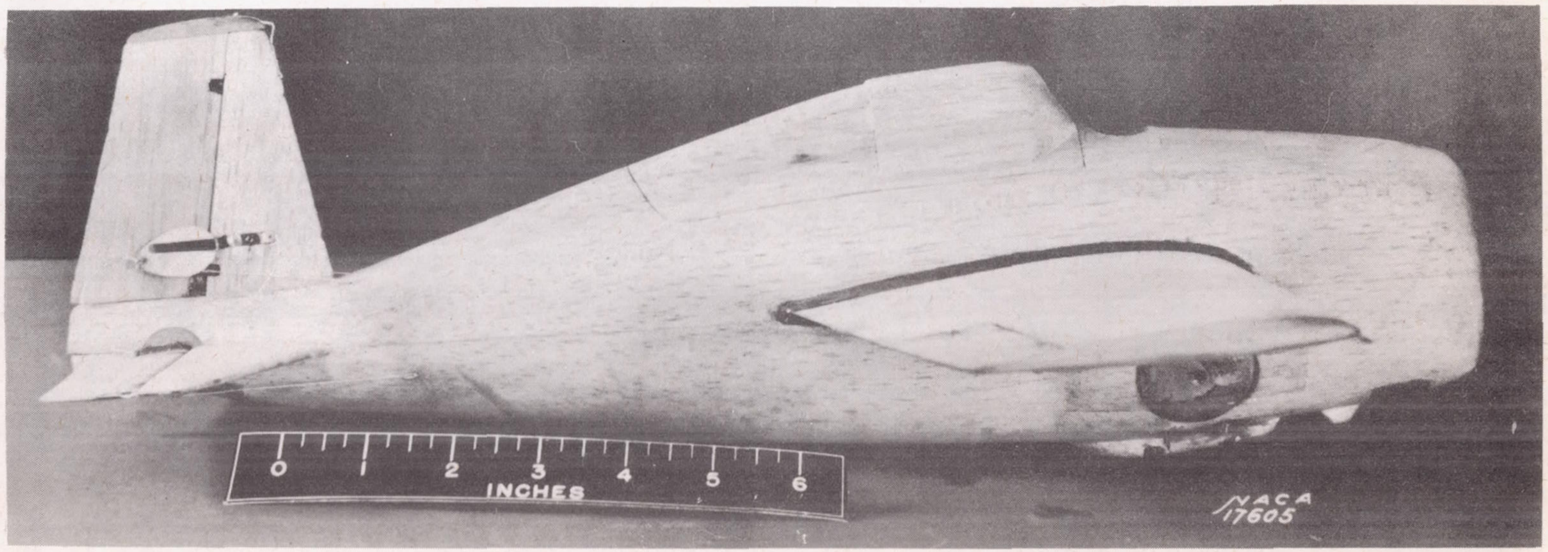


Figure 2.- Model II. A 1/18-scale model of the Grumman XF4F-3 airplane.

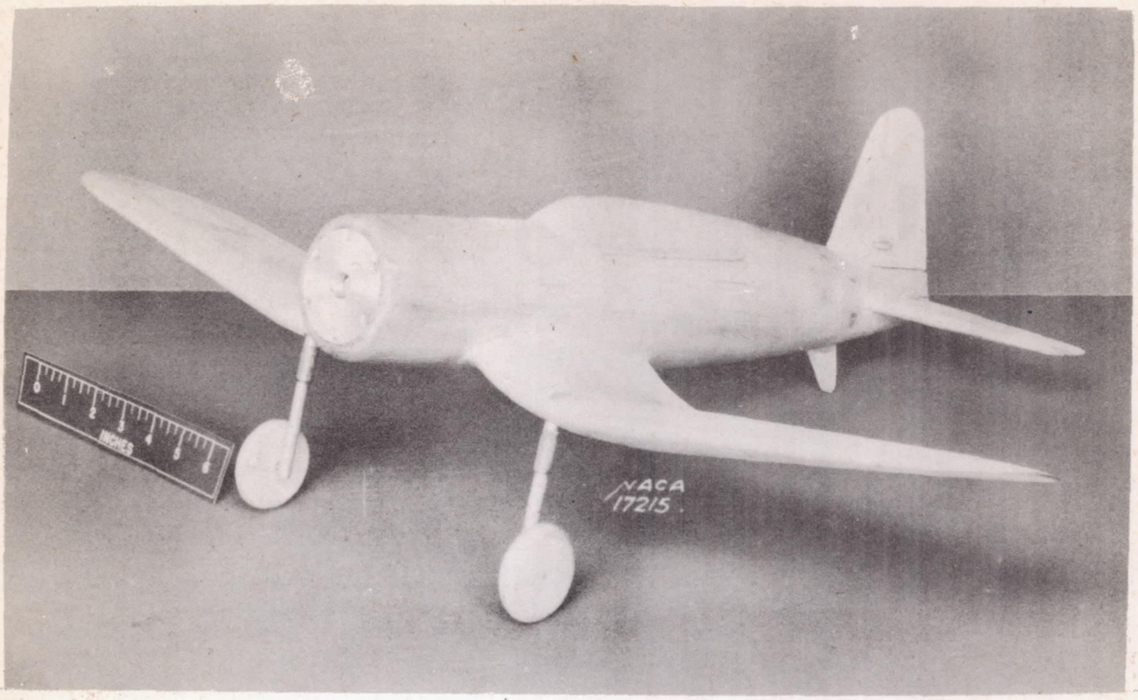


Figure 3.- Model III. A 1/20-scale model of the Vought-Sikorsky XF4U-1 airplane.

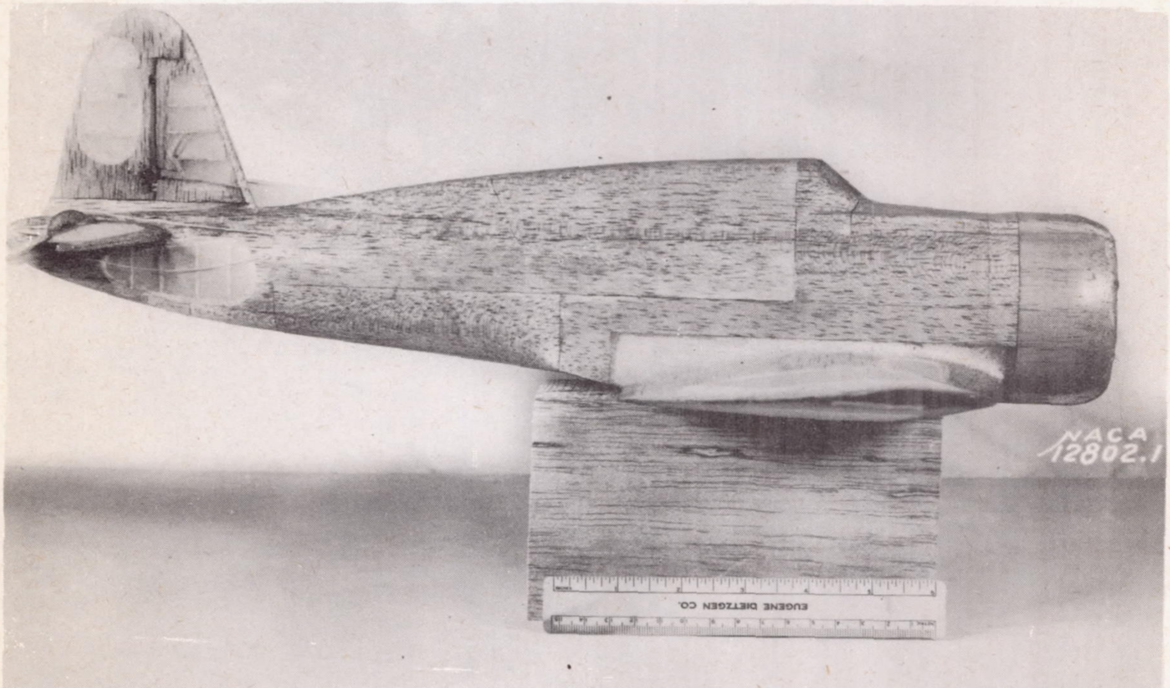


Figure 4.- Model IV. A 1/16-scale model of the Vought V-143 airplane (long tail).

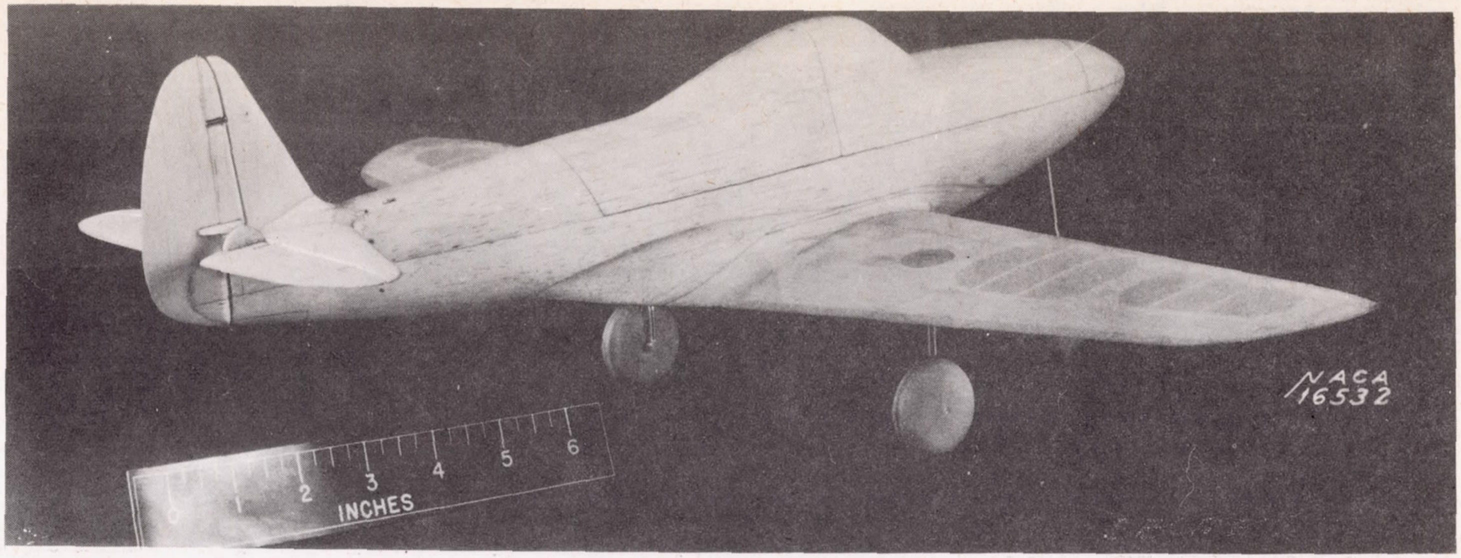


Figure 5.- Model V. A 1/20-scale model of the Bell XP-39 airplane.

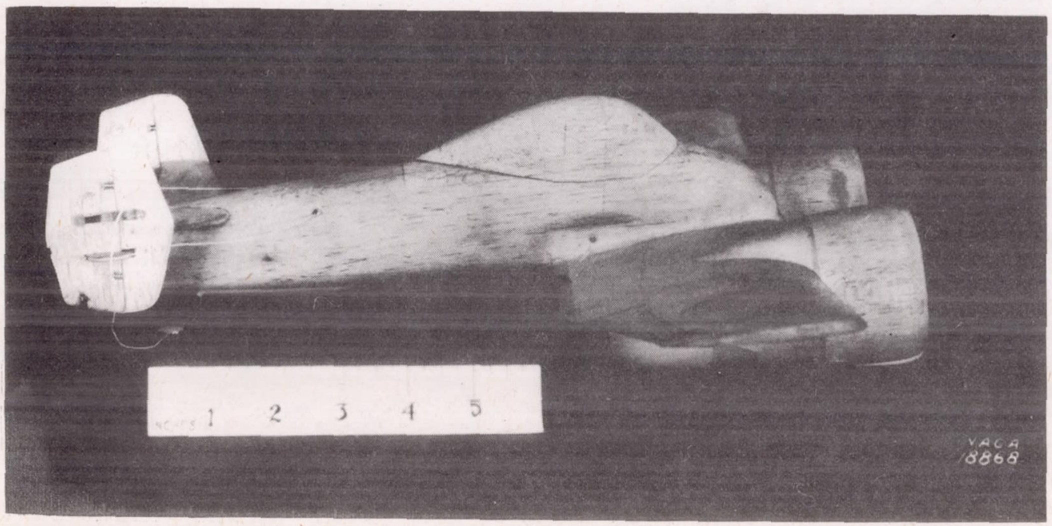


Figure 6.- Model VI. A 1/22-scale model of the Grumman XF5F-1 airplane.