NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2134

COMPARISON OF MODEL AND FULL-SCALE SPIN TEST RESULTS FOR 60 AIRPLANE DESIGNS

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SUMMARY

The results of Langley spin-tunnel investigations have been compared with corresponding full-scale results available for 60 different airplane designs. The purpose of the comparison was to determine the reliability of the model results in predicting full-scale spin and recovery characteristics.

Analysis of the data showed that model tests satisfactorily predicted full-scale recovery characteristics approximately 90 percent of the time. For the remaining 10 percent of the time, the model results were of value in predicting some of the details of the full-scale spins. Generally, when the models spun at angles of attack less than 45°, the corresponding airplanes spun at larger angles of attack; and when the models spun at angles of attack greater than 45°, the corresponding airplanes spun at smaller angles of attack. When the tail-damping ratio was greater than 0.02, the models spun with higher rates of rotation than the airplane; and when it was less than 0.02, the models spun with lower rates of rotation. Generally, the models spun with less altitude loss per revolution than the corresponding airplanes, but a higher rate of descent was found to be associated with the smaller angle of attack, whether of airplane or model. The airplanes generally spun with the inner wing down more than the inner wing of the corresponding models.

Predictions of emergency-recovery-parachute sizes based on model results were found to be somewhat conservative.

INTRODUCTION

The Langley 20-foot free-spinning tunnel is utilized to determine the spin and recovery characteristics of airplanes by means of model tests. It is therefore desirable that the accuracy of the model tests in predicting full-scale spin results be known. In pursuit of this objective, a comparison of the available results of model and full-scale spin tests for 21 designs was reported in reference 1. The information available for that comparison was rather meager. Since that time more models have been tested and more full-scale data have become available and it was thought desirable that all these data be analyzed to determine the correlation between model and full-scale spin tests.

SYMBOLS

α	angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	wing tilt, angle between span axis and horizontal plane, degrees
V	rate of descent, feet per second
Ω	angular velocity about spin axis, revolutions per second
V/Ω	altitude loss per revolution, feet per revolution

Subscripts:

M	model
A	airplane

METHODS

The airplanes for which full-scale spin test data were available were designs typical of those in use from 1926 to 1948 and cover a wide range of design variables. The types included in this study range from biplanes to modern swept-wing designs.

The full-scale data were received from the Air Force, from the Navy, and from various aircraft manufacturers. The reports received usually were incomplete in that all the steady-spin parameters measured in the spin tunnel were seldom available for the full-scale airplane. Turns for recovery, altitude loss in the spin, weight, and center-of-gravity location were generally available. The angle of wing tilt, rate of rotation, and moments of inertia were very rarely given. The effects of differences in moments of inertia are important but when they were not given and when weights and center-of-gravity locations were found to be in fairly close agreement for model and airplane, the moments of inertia were assumed to be comparable. Instrument records of angles of attack and wing tilt in the spin were available in only a few instances. In the other instances, these angles were based on pilots' estimates. Altitudes during the spin were assumed to be from altimeter readings and possible inaccuracy of the altimeters and altimeter lag were not accounted for.

Because altimeter readings at various stages of the spin and recovery were given more often than rates of descent, and rates of rotation were seldom given, a comparison between scaled-up model and airplane altitude losses per revolution was found to be more convenient than a comparison of rates of descent.

In spin-tunnel investigations, only fully developed model spins are tested. In order to compare data correctly, therefore, the airplane results must also be from fully developed spins. A study of flight instrument records available indicated that full-scale spins of 2 turns or less are probably not fully developed. Depending on the airplane design and upon the method of entry into the spin, a fully developed spin may sometimes be entered in less than 2 turns, but in most cases a 2-turn spin is in the incipient spin stage and, therefore, such data were discarded for the present comparison. Experience has indicated that recovery attempted during the incipient spin will be easier than if attempted after the spin has become fully developed. The data used, therefore, were for spins of more than 2 turns.

In several instances data were available for two designs that were very similar, such as Air Force and Navy versions of the same design or subsequent versions of the same design which had received only minor modifications. In these cases, all the data were considered to apply to one design. When any design was modified appreciably, the basic design and the modified design were treated as two designs.

In order to make the recovery comparison, a definition of satisfactory recovery was necessary. Full-scale recovery requirements vary with the type of the airplane and, in general, only fighter and trainer airplanes are required to demonstrate fully developed spins (spins of more than 2 turns). Air Force specifications (reference 2) require spin tests with maximum rearward center-of-gravity location, maximum wing-heavy loading, and maximum fuselage-heavy loading for control positions which include rudder full with the spin, elevator full up, and ailerons neutral, full with, and full against the spin. Recoveries from all spins in 2 turns or less by reversal of rudder followed approximately 1/2 turn later by downward movement of the elevator are desired. Navy specifications do not specify loading conditions but require various spin-entry techniques and control positions during the spin, which include rudder full with the spin, elevator full up, and ailerons neutral, 1/3 with, and 1/3 against the spin. Recoveries are desired in 1 turn or less by reversal of rudder to 2/3 against the spin followed approximately 1/2 turn later by downward movement of the elevator, but in certain cases consistent recovery in more than 1 turn may be considered satisfactory. To sum up the full-scale requirements into one comprehensive standard by which full-scale results were judged for the purpose of this paper, the following statement can be made: Recovery characteristics of the airplane were considered satisfactory if, from all fully developed spins for which data were available, recovery was consistently obtained in 2 turns or less by reversal of the rudder from with the spin to against the spin, movement of the elevator down, and neutralization of the ailerons.

Model spin-recovery requirements, which are designed to predict full-scale recovery characteristics, are that recoveries from spins with the normal control configuration for spinning (ailerons neutral, elevator full up, rudder with) by rudder reversal alone or a combination of rudder and elevator reversal take 2 turns or less. In order to evaluate the effects of slight deviations of the controls from the normal spinning control configuration, of cable stretch, or of high forces which might prevent full control deflection, tests are also made with the ailerons set 1/3 of the maximum deflection in the direction conducive to slower recoveries, the elevator set at 2/3 up or full up, whichever is conducive to slower recoveries, and the rudder movement for recovery to 2/3 against rather than to full against the spin. The elevator movement, when used for recovery, is generally to 1/3 or 2/3 down. Recovery characteristics are not considered satisfactory for models unless recovery is obtained from this criterion spin in $2\frac{1}{4}$ turns or less.

PRECISION

The model spin data presented are believed to be the true values given by the model within the following limits:

α, degrees . . . . ±1
ϕ, degrees . . . . ±1
V/Ω, percent . . . . ±7

The limits of accuracy of the full-scale data were not known. These limits varied with the accuracy of flight instruments and with the pilots' estimates.

RESULTS AND DISCUSSION

Recovery Characteristics

In determining the accuracy of model tests in predicting full-scale spin results, the prediction of recovery characteristics is of most importance. In table I the results of recovery tests of 60 airplanes for which data were available are compared with spin-tunnel results obtained with corresponding models. These data show agreement in recovery characteristics for 53 cases. Of the seven cases that were considered in disagreement, three were cases in which model recovery results were optimistic compared with full-scale results and four were cases in which model recovery characteristics were conservative. Of these seven cases, four were cases (see footnotes of table I) in which the disagreement was not great - that is, the full-scale and model results were similar in many details and the model data were believed to be of value in anticipating full-scale results. The three remaining cases of disagreement were cases in which the only facts known about the full-scale spins were the recovery characteristics based on limited full-scale data. It appears that these spin-tunnel results accurately predict full-scale recovery characteristics from fully developed spins approximately 90 percent of the time; for the remaining 10 percent of the time, the model results are of value in predicting some details of the full-scale spins, such as proper recovery technique, aileron effects, and motion in the developed spins.

As previously mentioned, experience has indicated that recoveries attempted during the incipient spin are faster than recoveries attempted after the spin has become fully developed. This conclusion was supported by results of spin tests of 16 additional designs for which only full-scale data for spins of 2 turns or less were available. Airplane recoveries were satisfactory for all 16 designs, although, for four of these designs, model tests indicated that unsatisfactory recoveries were possible from fully developed spins.

Angle of Attack

Data concerning the angle of attack in the fully developed spin were available for 28 designs. The difference between the model and airplane angles of attack was plotted against model angle of attack in figure 1 which shows that, in general, when the model spin was at an angle of attack less than 45°, the corresponding airplane spin was at a larger angle of attack, but that when the model spin was at an angle of attack greater than 45°, the corresponding airplane spin was at a smaller angle of attack. This figure indicates that the airplanes tended to spin at an angle of attack closer to 45° than did the corresponding models.

The spread of points may be attributable to lack of precision of pilots' estimates of angles of attack, lack of detail in model construction, and probable differences in loadings between airplane and model.

Rate of Rotation

Data concerning rate of rotation in a spin were available for 15 designs. The differences between the model and airplane rates of rotation were plotted against tail-damping ratio (determined by method of reference 3) and are presented in figure 2. These data show that, for tail-damping ratios greater than 0.02, the model rates of rotation were greater than those of the airplane; whereas, for values less than 0.02, the model rates of rotation were less than those of the airplane.

Altitude Loss per Revolution

Table II presents the data available pertaining to altitude loss per revolution. Data were available for 33 comparisons and the airplane generally had a higher altitude loss per revolution than the scaled-up model value. In four of the five cases in which the model altitude loss per revolution was greater, the difference was small enough so that altimeter lag and inaccuracies could account for the difference. In order to determine the relationship between model and airplane rates of descent, computations were made with the use of the V/Ω data and values of Ω which were available from tests or were estimated from figure 2. The results showed that of the 28 cases for which these data and angle-of-attack data were available, 23 showed a greater rate of descent associated with the smaller angle of attack whether it was for the model or the airplane.

Angle of Wing Tilt

Comparison of the data presented in table III for 15 designs show that, in all cases but three, the inner wing (right wing in a right spin) of the airplane was tilted down more during the spin than was the inner wing of the corresponding model. In the three cases in which the model wings were tilted more inward, the differences between model and airplane values were so small as to be less than the probable limits of accuracy of the data.

Emergency Spin-Recovery Parachutes

Data presented in table IV show a comparison of the requirements for emergency spin-recovery parachutes for model and airplane for six designs. The model parachute requirements were slightly conservative in three cases - that is, the model predicted a somewhat larger parachute than was necessary - and very conservative in two cases. These data seem to indicate that parachute-size predictions based on model results are generally conservative. This effect is to be expected inasmuch as the model rudder is generally maintained with the spin during parachute tests.

CONCLUSIONS

Based on the results of model and full-scale spin tests of 60 designs for which data were available, the following conclusions as to the application of model results in predicting full-scale spin results were drawn:

1. Model recovery tests satisfactorily predicted full-scale recovery characteristics about 90 percent of the time. For the remaining 10 percent of the time, the model tests were of value in predicting some of the details of the full-scale spins.

2. When the model spin was at an angle of attack less than 45°, the airplane spin generally was at a larger angle of attack; whereas, when the model spin was at an angle of attack greater than 45°, the airplane spin generally was at a smaller angle of attack than that indicated by the model - that is, the airplanes tended to spin at an angle of attack closer to 45° than did the corresponding models.

3. For values of tail-damping ratio greater than 0.02, the model rates of rotation were generally higher than those of the airplane; whereas, for values of tail-damping ratio less than 0.02, the model rates of rotation were generally lower than those of the airplane.

4. The model generally spun with a lower altitude loss per revolution than that of the corresponding airplane. Higher rate of descent of airplane or model, however, was generally associated with the smaller angle of attack; that is, when an airplane spun at a smaller angle of attack, it generally had a higher rate of descent than the corresponding model, and when the model spun at a smaller angle of attack, the model had the higher rate of descent.

5. The airplane generally spun with the inner wing tilted down more than the inner wing of the corresponding model.

6. Predictions of emergency-parachute sizes based on model results were somewhat conservative.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., April 28, 1950

REFERENCES

1. Seidman, Oscar, and Neihouse, A. I.: Comparison of Free-Spinning Wind-Tunnel Results with Corresponding Full-Scale Spin Results. NACA MR, Dec. 7, 1938.

2. Anon.: Spinning Requirements for Airplanes. AAF Specification No. 1816, June 15, 1945.

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

TABLE I.- COMPARISON OF MODEL AND AIRPLANE RECOVERY CHARACTERISTICS

Design	Simulated altitude of model tests (ft)	Model recovery characteristics	Average altitude of airplane tests (ft)	Airplane recovery characteristics	In agreement
1	8,500	Satisfactory	9,000	Satisfactory	Yes
2	4,000		------		
3	6,000		------		
4	4,000		------		
5	4,000		------		
6	10,000		------		
7	6,000		10,000		
8	10,000		9,000		
9	4,000		12,000		
10	8,000		------		
11	12,000		8,000		
12	6,000		------		
13	7,000		------		
14	8,000		11,000		
15	14,000		7,300		
16	10,000		7,000		
17	12,000		16,000		
18	8,500		------		
19	12,000		9,000		
20	10,000		8,000		
21	10,000		11,500		
22	10,000		12,500		
23	10,000		10,000		
24	6,000		12,000		
25	10,000		7,000		
26	18,000		17,000		
27	20,000		10,500		
28	15,000		22,000		
29	15,000		------		
30	15,000		------		
31	10,000		16,500		
32	15,000		25,000		
33	15,000		15,000		
34	10,000		------		
35	6,000	Unsatisfactory	3,000	Unsatisfactory	
36	8,500		9,000		
37	10,000		------		
38	10,000		17,000		
39	6,000		9,000		
40	6,000		15,000		
41	12,000		16,000		
42	15,000		------		
43	18,000		17,000		
44	15,000		------		
45	20,000		10,500		
46	15,000		18,000		
47	10,000		------		
48	15,000		15,000		
49	10,000		------		

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TABLE I.- COMPARISON OF MODEL AND AIRPLANE RECOVERY CHARACTERISTICS - Concluded

Design	Simulated altitude of model tests (ft)	Model recovery characteristics	Average altitude of airplane tests (ft)	Airplane recovery characteristics	In agreement
50	10,000	Marginal	------	Marginal	Yes
51	18,000	Marginal	14,000	Marginal	Yes
52	15,000	Recoveries to left satisfactory; recoveries to right somewhat marginal	13,000	Recoveries to left satisfactory; recoveries to right satisfactory but slower than left	Considered yes
53	10,000	Marginal	14,000	Satisfactory by special control technique	Considered yes
54	6,000	Satisfactory	7,000	Unsatisfactory	No (model results optimistic)
[a]55	10,000	Satisfactory	3,000	Unsatisfactory	No (model results optimistic)
[b]56	15,000	Marginal	5,000	Unsatisfactory	Considered no (model results optimistic)
57	8,000	Unsatisfactory	10,500	Satisfactory	No (model results conservative)
58	5,000	Unsatisfactory	18,000	Satisfactory	No (model results conservative)
[c]59	10,000	Unsatisfactory	10,000	Satisfactory	No (model results conservative)
[d]60	20,000	Unsatisfactory	------	Satisfactory	No (model results conservative)

[a]The model results indicated satisfactory recoveries but also showed that premature movement of the elevator down might be detrimental. The airplane results indicated two types of spin, one a steep type with satisfactory recoveries and one a flat type from which recovery could not be obtained. Recoveries, at the time this airplane was tested (1926), were generally attempted by reversal of the elevator followed by reversal of the rudder. This recovery technique might explain the unsatisfactory recoveries. The recovery technique used for this airplane is not known and, therefore, because of the doubt, it is listed under disagreement.

[b]Model results indicated a very oscillatory spin and that rudder reversal would not cause satisfactory recovery but that rudder reversal followed by elevator reversal to full down would be satisfactory. The airplane spins were oscillatory much the same as the model, and reversal of the rudder alone was ineffective. Reversal of the rudder and elevator was very critical and resulted in a 5-turn recovery once and an emergency parachute recovery a second time. Spin-tunnel results were accurate in all details except the effectiveness of the elevator.

[c]Model results showed satisfactory recoveries from the normal control configuration for spinning (elevator up, ailerons neutral) but unsatisfactory recoveries from the criterion spin (ailerons 1/3 against the spin). Airplane tests showed satisfactory recoveries, but a pilot who had made extensive spin tests of this airplane visited the spin tunnel and reported that, with ailerons neutral, recoveries were satisfactory but that, with ailerons against the spin, recoveries could not be obtained by normal use of the rudder and elevator and that movement of the ailerons to with the spin was necessary for recovery. The amount the ailerons were held against the spin by this pilot was not known and, inasmuch as other reports stated that recovery characteristics of this airplane were satisfactory, it was decided to call this a disagreement.

[d]Model results indicated very oscillatory spins and that recoveries varied with the phase of the oscillation in which they were tried. Some satisfactory and some unsatisfactory recoveries were obtained and on this basis a modification was recommended for the airplane. Airplane spins were very similar to model results in the nature of the spin, rate of rotation, and rate of descent, but recoveries were satisfactory from all spins.

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TABLE II.- COMPARISON OF MODEL AND AIRPLANE ALTITUDE

LOSSES PER REVOLUTION

Design	$(V/\Omega)_A - (V/\Omega)_M$ (ft/rev)	$\frac{(V/\Omega)_A - (V/\Omega)_M}{(V/\Omega)_A}$
7	50	0.14
8	100	.25
9	18	.04
[a]9a	0	0
12	335	.42
13	-33	.13
14	60	.14
16	92	.24
[a]16a	26	.09
17	34	.03
18	16	.06
19	5	.01
20	3	.01
21	153	.26
22	67	.10
23	20	.05
24	500	.50
25	7	.01
27	8	.01
31	260	.33
32	470	.31
35	-6	.03
36	-19	.08
38	102	.16
39	46	.10
40	195	.31
43	-100	.33
52	134	.20
53	141	.19
55	-19	.12
57	300	.69
58	1200	.86
60	491	.41

[a]a indicates a modification of the original design.

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TABLE III.- COMPARISON OF MODEL AND AIRPLANE

ANGLES OF WING TILT

Design	ϕ_M (deg) (a)	ϕ_A (deg) (a)
5	4U	6D
7	3D	20D
9	0	23D
13	15U	4U
14	2D	0
23	2D	0
26	3U	10D
[b]26a	2D	5D
27	6D	0
32	1U	10D
35	7U	6D
36	7U	1U
39	0	20D
55	14D	20D
59	2U	13D

[a] U indicates inner wing up; D indicates inner wing down.
[b] a indicates a modification of the original design.

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TABLE IV.- COMPARISON OF EMERGENCY SPIN-RECOVERY TAIL-PARACHUTE SIZES REQUIRED BY MODEL AND AIRPLANE

Design	Model parachute diameter (full scale) (ft) (a)	Airplane parachute diameter (ft)
14	12.0	8.0
27	>11.9	8.0
40	8.0	7.0
43	8.0 Rudder neutralized	6.0 Did not effect recovery
52	8.0	6.0
56	7.5	7.5

[a]Rudder maintained with the spin unless otherwise noted.

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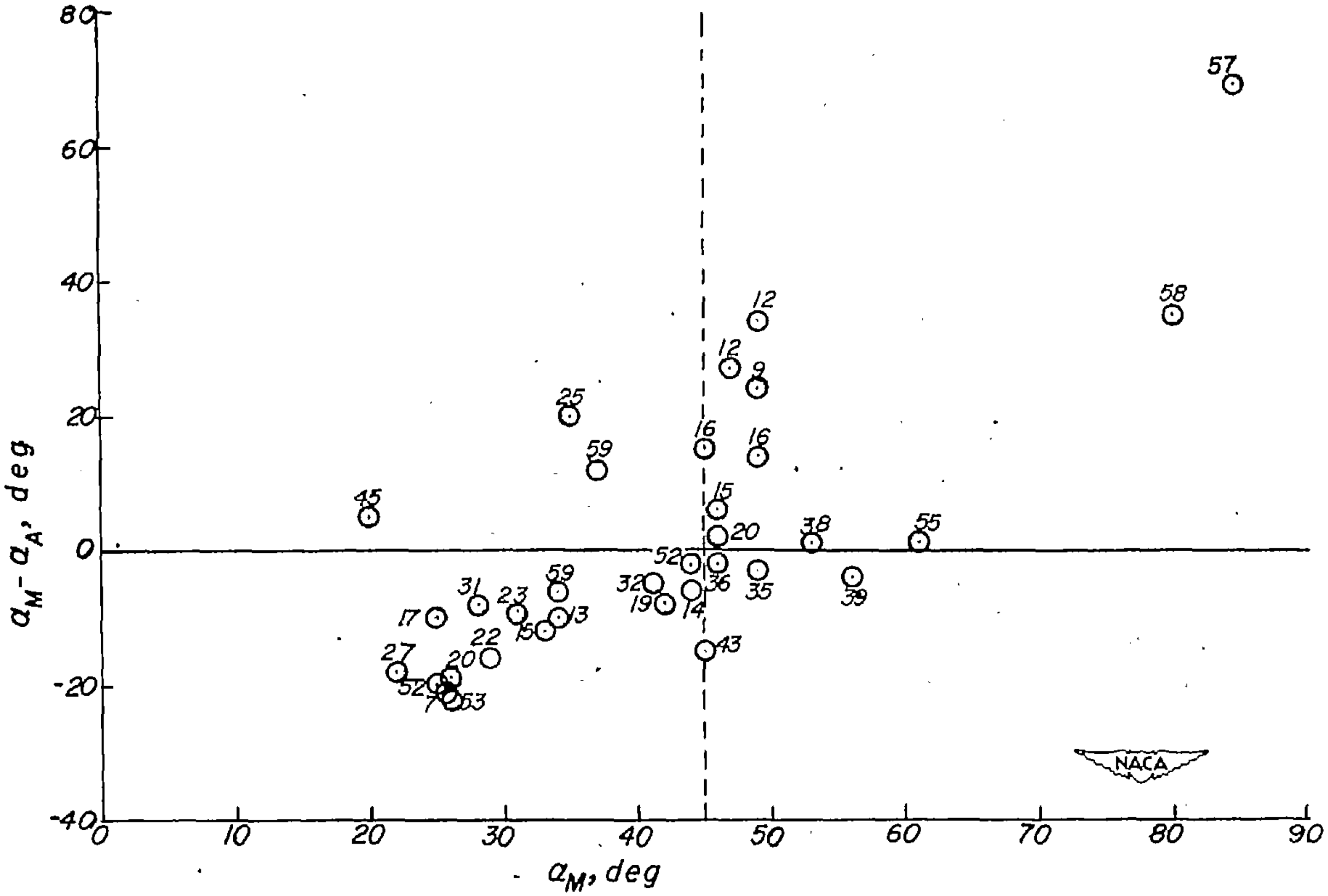

Figure 1.- Difference between airplane and model angles of attack plotted against model angles of attack obtained in the Langley 20-foot free-spinning tunnel. (Numbers refer to design numbers in table I.)

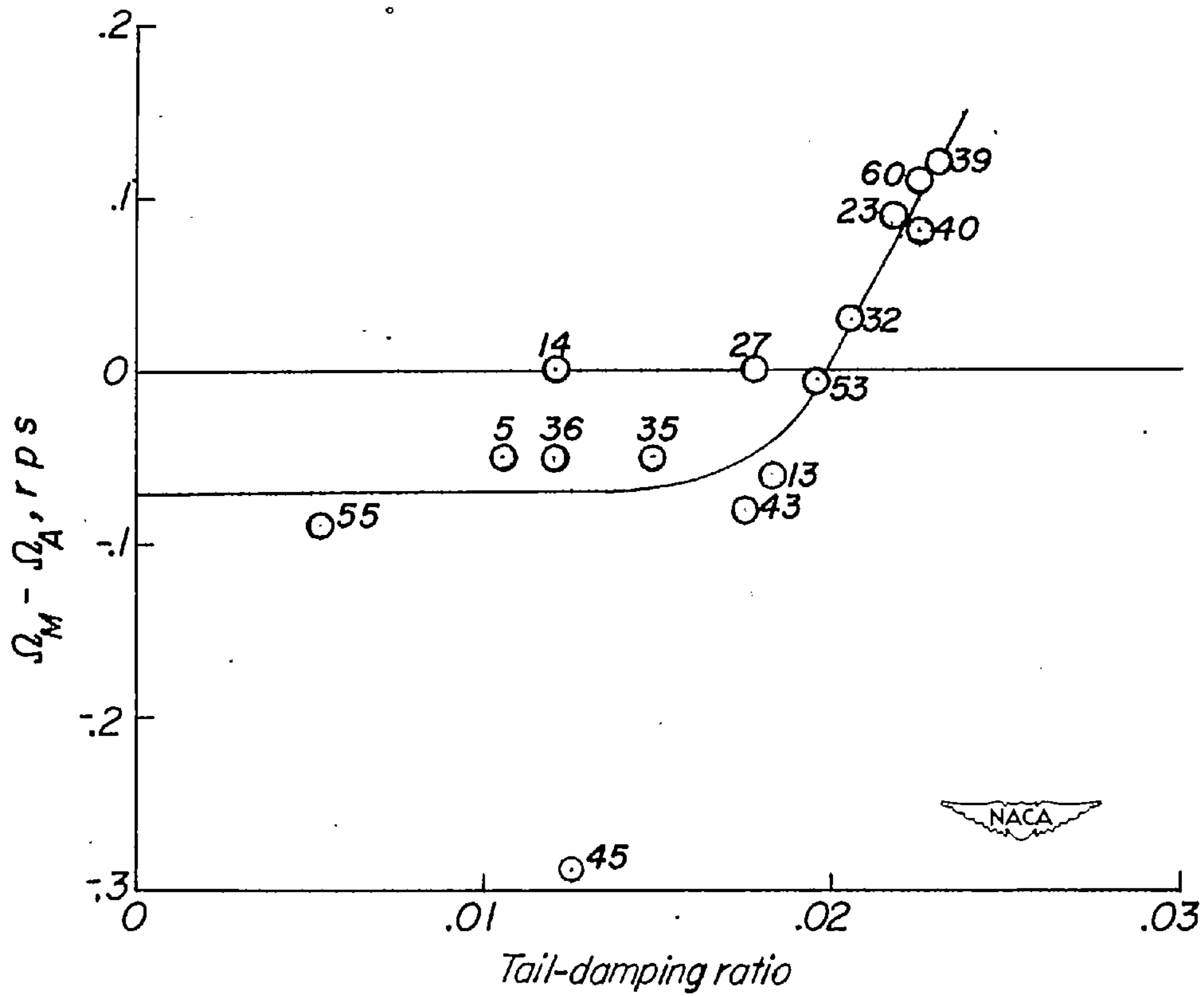

Figure 2.- Difference between airplane and model rates of rotation plotted against the tail-damping ratio of the design. (Numbers refer to design numbers in table I.)