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## COMPARISON OF FREE-SPINNING WIND-TUNNEL RESULTS WITH CORRESPONDING FULL-SCALE SPIN RESULTS


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MEMORANDUM REPORT

# COMPARISON OF FREE-SPINNING WIND-TUNNEL RESULTS WITH CORRESPONDING FULL-SCALE SPIN RESULTS

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## SUMMARY

A study of comparable information on available full-scale spinning results and NACA free-spinning wind-tunnel results was made by the NACA to determine the degree of reliability of tunnel results in predicting the spinning behavior of airplanes. Full-scale spin results, mainly of a qualitative nature, were available for 21 airplanes. These results have been compared to corresponding results on models of the airplanes tested in the NACA free-spinning wind tunnel.

The comparison of available recovery results showed general satisfactory agreement between model and airplane in 16 instances and disagreement in five instances, two of which were for almost identical airplanes. The model results that gave disagreement with full-scale results, however, usually agreed in some of the details such as direction of aileron effect. Using these comparisons as a criterion, it may be stated that the free-spinning wind tunnel can be expected to predict full-scale spin characteristics accurately about 80 percent of the time.

## INTRODUCTION

The NACA free-spinning wind tunnel is being utilized for two purposes. On the one hand, fundamental research is being carried out in the field of spinning, covering such phases as: relative merits of different wing or tail arrangements, effects of loading, etc. On the other hand, routine model spin tests are conducted for every service airplane in the categories for which spinning is permitted in an attempt to prevent the occurrence of dangerous spinning characteristics in the production machines. In this work it is appreciated that, owing to various incidental effects inherent in model testing, conclusions drawn from wind-tunnel tests of small-scale models are occasionally in error.

Such factors as propeller-couple and slipstream effects and speed of control manipulations, which are not simulated on the model, also may affect the results.

In order to evaluate and, if possible, improve the accuracy with which the model results can be used to predict full-scale spin characteristics, it is necessary to compare model and full-scale results for a number of different designs. At present the Committee has completed routine free-spinning tests on 21 specific models. For three of these models, comparative full-scale tests were conducted by the Committee. The results of these tests are treated in detail in reference 1 and in an unpublished comparison. These comparisons were made on a quantitative basis and generally indicated wherein the model tests may differ from the full-scale spins. It would be desirable if such complete comparisons could be made for all models tested in the spin tunnel, but such a procedure is not practical because of the time and expense of obtaining complete flight spin data.

As an alternate means of obtaining a comparison of a large number of model and corresponding airplane spins in order to determine the extent to which model and airplane results differ, the Committee sent requests to the Navy Bureau of Aeronautics and to the Army Air Corps for their information on the full-scale spin characteristics of airplanes, models of which had been spin-tested in the NACA spinning tunnel. Although the information thus obtained was of a qualitative nature and in many cases very limited, a comparison of spin-tunnel and full-scale recovery results has been made for whatever comparable data were made available. The present report gives comparisons of model and full-scale results for the 21 models tested in the free-spinning wind tunnel.

## RESULTS AND DISCUSSION

The previously mentioned detailed comparisons of model and full-scale steady-spin characteristics on two biplanes (reference 1) and on a monoplane (unpublished data) indicated that, for a given loading and control setting, model results show a somewhat smaller angle of attack, higher rate of descent, and from $5^{\circ}$ to $10^{\circ}$ more outward sideslip at a given angle of attack.

The NACA has completed free-spinning wind-tunnel tests on models of 21 military airplanes to date and corresponding full-scale spin information has been obtained on recovery characteristics for these airplanes. A summary of the results of comparison between model and flight is given in table I which shows general agreement between the spin-tunnel and full-scale results in 16 cases and disagreement in five cases, two of the disagreements being for similar airplanes.

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A brief presentation of available results used in preparing table I follows:

Airplane 1:

Model and full-scale spin tests were made by the NACA and the steady-spin and recovery results presented in reference 1. Numerous tests were made and it was concluded that the model results satisfactorily checked the full-scale results.

Airplane 2:

Tests on both model and airplane were also made for this biplane by the NACA and the steady-spin and recovery results presented in reference 1. In this case also, numerous tests led to the conclusion that in general the agreement between model and full-scale results was satisfactory.

Airplane 3:

Tests on the model of airplane 3 in the spin tunnel indicated that correct control manipulation would give rapid recoveries but that slow recoveries, and even no recovery, could be obtained from spins with adverse loading, elevators down, and ailerons against the spin (right aileron down in a right spin). Preliminary tests on the airplane were terminated when the airplane "spun in" after several previous satisfactory recoveries from spins. Model results can be used as a basis for an explanation of the results obtained on the airplane and thus indicate agreement with the full-scale results.

Airplane 4:

Spin tests of the model of airplane 4 in the spin tunnel gave results similar to those on the model of airplane 3, indicating rapid recoveries for correct control manipulation (rudder reversal before moving the elevators down) and slow recoveries for adverse loading or improper control disposition. The full-scale airplane was spun 10 turns to the right and 10 turns to the left with recovery in one turn. Assuming that the control manipulation used corresponded to that recommended in the model test report, this constitutes agreement in results.

Airplane 5:

The results of model spin tests of airplane 5 indicated satisfactory recovery characteristics. The model gave a nose-down spin when the controls were with the spin and recovery took place in about one turn by complete reversal of both controls. When the controls were neutral, the model would not spin. Tests on the full-scale airplane gave similar results, the airplane giving a steep spin from which recovery could be obtained in one and one-half turns. If the controls were merely released, the airplane would recover from the spin.

Airplanes 6 and 6a:

Spin tests of models of airplanes 6 and 6a indicated oscillatory spins from which recovery would be rapid if the rudder was reversed while the elevators were full up. Deviations from this method of recovery, the model indicated, would lead to slower recoveries. Model tests also indicated that the airplane would be very sensitive to loading changes, certain deviations from normal loading leading to poor recoveries. Full-scale spin tests on the airplanes indicated steep, oscillatory spins from which recovery was reported to have been satisfactory. It is understood, however, that difficulty in spins has been encountered and that further spinning of this design is now prohibited. The behavior of the airplane thus appears quite similar to that of the model.

Airplane 7:

Tests on the model of this airplane indicated fast recoveries for rudder reversal with elevators up, but rudder reversal after the elevators had been moved down led to flat spins from which recovery was very difficult. Aft movement of the center of gravity retarded recovery. Full-scale spin tests on this airplane indicated that improper control manipulation would make for flat-spinning tendencies and unsatisfactory recovery characteristics. Moving the center of gravity aft also would make for slow recoveries. Proper control manipulation on the airplane, it was indicated, would give satisfactory recoveries. Model and full-scale results thus indicate agreement.

Airplane 8:

Tests of the model of airplane 8 in the spin tunnel indicated satisfactory recovery for simultaneous reversal of both controls and for rudder reversal with elevators up. Recoveries from spins by reversing the rudder after the elevators were moved down were slow. The full-scale spin tests indicated rapid recovery from 10-turn spins both to the right and left. On the assumption that the pilot used normal control manipulation (reversing the rudder before or simultaneously with the elevators), this constitutes agreement with the model results.

Airplane 9:

Results of spin tests of the model of airplane 9 indicated that rudder reversal before moving the elevators down would give results similar to those for the model of airplane 8, but indicated that recovery would be unsatisfactory if attempted by simultaneous reversal of both controls for the fighter loading with landing gear extended. Preliminary full-scale spin tests on airplane 9 were terminated by a crash due to failure to recover from an apparently similar condition. Model tests with other loadings, however, indicated fairly satisfactory recoveries and indicated that if the rudder was completely reversed before moving the elevators down, satisfactory recovery could be obtained for all conditions. All recoveries on the rebuilt airplane 9 were made by first reversing the rudder and then moving the elevators down and required less than three and one-half turns. Spins with landing gear down gave poorer recoveries for both model and airplane than with gear up. The agreement between model and flight results for this airplane is considered to be very good.

Airplane 10:

Model spin tests of airplane 10 indicated satisfactory spinning characteristics, giving fairly rapid recoveries by rudder reversal for all elevator settings, recoveries being slowest, however, for rudder reversal with elevators down. Full-scale spin tests also indicated satisfactory spinning characteristics, the final demonstration consisting of six spins and recoveries.

Airplane 11:

Results of spin tests on the model of the airplane 11 indicated rapid recovery for the normal loading for rudder reversal for all elevator settings. With both controls neutral, the model would not spin. It was indicated that under adverse loading conditions, having the elevators down before reversing the rudder would lead to slow recoveries. Flight results on the normal airplane indicated rapid recoveries by normal control manipulation as well as by neutralizing both controls, thus checking the tunnel results closely.

Airplane 12:

Spin tests of the model of airplane 12 indicated rapid recovery by rudder reversal or by reversal of both rudder and elevators with the ailerons neutral. Deflecting the ailerons with the spin (right ailerons up in a right spin) gave faster recoveries. A disagreement with these results is reported by the pilot who made the flight demonstration. In the course of two preliminary spins there were indications that recovery by reversal of rudder alone with the elevators held up would require more than two turns and by moving the elevators down after the rudder had been reversed would require more than one turn. The pilot found that to expedite recovery it was necessary to deflect the ailerons with the spin and, by including this manipulation, successfully passed the demonstration tests. The beneficial aileron effect of deflecting ailerons with the spin, as predicted by the tunnel, was thus verified, although the results of the preliminary spins by the pilot definitely disagree with the model indications.

Airplanes 13 and 13a:

Tests on models of airplanes 13 and 13a in the spin tunnel indicated satisfactory spin characteristics. Full-scale experience with this airplane type has varied widely, some pilots reporting excellent recovery characteristics while others reported unsatisfactory recoveries. Flight tests by the NACA indicated satisfactory recovery characteristics in general. Recovery by rudder reversal alone with elevators held up was unsatisfactory, however, for a right spin although satisfactory for the left spin. The model results did not indicate possible bad spins apparently obtainable occasionally in flight and, on the basis of this inconsistency, model and airplane results are not considered to check satisfactorily.

Airplane 14:

Tests of the model of airplane 14 indicated unsatisfactory spinning characteristics for the original model with short tail but satisfactory spinning characteristics for the final model with the lengthened and revised tail. Full-scale spin tests on both versions of this airplane gave results very similar to those indicated by the tunnel. This information was obtained verbally from the manufacturer's representatives.

Airplane 15:

Tests in the spinning tunnel on a model of airplane 15 led to the design of a new tail arrangement which gave very satisfactory recovery characteristics for both landplane and seaplane models. With a tail similar to that derived at the spin tunnel installed on the full-scale airplane, extensive spin tests for both landplane and seaplane by the manufacturer gave very satisfactory spin results.

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Airplane 16:

Results of model tests in the spinning tunnel indicated unsatisfactory recovery characteristics for airplane 16, except for large aileron deflections with the spin. Results of numerous full-scale spin tests generally indicated satisfactory recoveries, but one case is reported for which recovery was difficult. If it is assumed that the slow recovery resulted from failure to deflect the ailerons with the spin, this constitutes a partial agreement with tunnel results. As full-scale results indicate satisfactory recoveries in general, it is concluded that model results are too conservative and do not constitute a satisfactory check with full-scale results.

Airplane 17:

Model tests of airplane 17 indicated that satisfactory recoveries would be obtained by complete rudder reversal followed by movement of the elevators from full up to full down, and that ailerons deflected with the spin would aid recovery. Model results indicated that moving the elevators down before reversing the rudder would give unsatisfactory recoveries. Extending the landing gear gave an adverse effect and deflecting the flap a slight favorable effect. Full-scale spin tests on airplane 17 indicated satisfactory recovery characteristics. The control manipulation used by the test pilot was complete rudder reversal followed by moving the elevators down and ailerons partially with the spin. As on the model, landing-gear extension gave an adverse effect and flap deflection a slight favorable effect. Results of model and flight results are considered to be in satisfactory agreement.

Airplane 18:

Results of model spin tests of airplane 18 indicated satisfactory recovery characteristics for both seaplane and landplane. Simultaneous reversal of both controls gave rapid recoveries as did also rudder reversal with the elevators up. Full-scale spin recoveries were made by rudder reversal followed by moving the elevators forward of neutral. Recoveries were very satisfactory and slightly faster than obtained with the model. Ailerons with the spin were beneficial and ailerons against the spin were adverse for both model and airplane and flaps had a slight beneficial effect. Model and flight results seem to agree very well.



Airplane 19:

Spin tests on the model of airplane 19 in the spin tunnel indicated that satisfactory recoveries could be obtained by reversing the rudder with the elevators held full up or by simultaneous reversal of both controls. Moving the elevators down before reversing the rudder would lead to slow recoveries. Tests in flight by several pilots gave results that ranged from satisfactory to unsatisfactory. The flight results as the whole were inconsistent and inconclusive. Two full-scale spins of the airplane by the NACA indicated poor recovery by rudder reversal with elevators up or by rudder reversal followed by elevators down. (Recovery was effected by putting the ailerons against the spin.) Comparison between NACA flight and model tests shows that the model rudder was relatively too effective in producing recovery from spins with elevators up. Results of model and full-scale tests are not considered to be in satisfactory agreement.

Airplane 20:

Spin tests on the model of airplane 20, a model very similar to the model of airplane 16, indicated definite unsatisfactory recovery characteristics, as was the case for the model of airplane 16. Model results gave no recovery unless the ailerons were deflected fully with the spin. Full-scale demonstration spin tests of the airplane indicated satisfactory recovery characteristics, although it is understood that a pilot encountered difficulty in attempting to recover from a spin during a preliminary test. As true for airplane 16, model results of airplane 20 are not considered to be in satisfactory agreement with full-scale results.

Airplane 21:

Spin-tunnel tests of the model of airplane 21 indicated steep unsteady spins with very high rates of descent from which recovery would be satisfactory. Full-scale spin tests of a modified airplane very similar to airplane 21 also gave steep, rough spins with high rates of descent from which recoveries were rapid.

## CONCLUDING REMARKS

Although it is appreciated that the information utilized as a basis of comparison was in some instances quite limited, the model results appear to be in good agreement with corresponding full-scale results. For 21 airplanes investigated there was satisfactory agreement in 16 cases and disagreement in five cases, two of which were for a similar type airplane. For this type (airplanes 16 and 20) model results were too conservative, indicating unsatisfactory recoveries for normal movements of controls. In flight, satisfactory recoveries were obtained in the great majority of cases. For the other three airplanes (airplanes 12, 13, and 19) for which tunnel and flight results disagree, the disagreement is of a similar nature for all three airplanes. The tunnel results indicate satisfactory recoveries from spins by rudder reversal with elevators up or by reversal of both controls, but flight results indicate possible unsatisfactory recoveries from such control dispositions. For the cases of disagreement between model and airplane results, however, there was agreement in some of the details, such as, for example, direction of aileron effect.



It is hoped that in the future more complete data will be recorded for all full-scale spin tests. A useful aid to the pilot in verifying control manipulation is the control-position recorder recently developed by the NACA. Detailed full-scale information will be a great aid in comparing NACA spin-tunnel results with flight results and should lead to the most efficient utilization of the NACA spin-tunnel facilities.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 7, 1938.

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TABLE I

COMPARISON OF LANGLEY SPIN-TUNNEL RESULTS WITH

FULL-SCALE SPIN RESULTS FOR VARIOUS AIRPLANES

| Airplane | Type | Agreement of model and full-scale results | Reference | Additional information |
|---|---|---|---|---|
| 1 | Trainer | Satisfactory | 1 | |
| 2 | Fighter | Satisfactory | 1 | |
| 3 | Scout | Satisfactory | ------------ | |
| 4 | Light bomber | Satisfactory | ------------ | |
| 5 | Fighter | Satisfactory | ------------ | |
| 6, 6a | Light bombers | Satisfactory | ------------ | Verbal |
| 7 | Trainer | Satisfactory | ------------ | |
| 8 | Fighter | Satisfactory | ------------ | |
| 9 | Fighter | Satisfactory | ------------ | |
| 10 | Scout-bomber | Satisfactory | ------------ | |
| 11 | Trainer | Satisfactory | 2 | |
| 12 | Fighter | Unsatisfactory | Unpublished data | |
| 13, 13a | Trainers | Unsatisfactory | 3, 4, 5, 6 | |
| 14 | Fighter | Satisfactory | ------------ | Verbal (from manufacturer's representative) |
| 15 | Observation-scout | Satisfactory | 2 | |
| 16 | Fighter | Unsatisfactory | 7 | |
| 17 | Fighter | Satisfactory | ------------ | Verbal (NACA pilot) |
| 18 | Observation-scout | Satisfactory | Unpublished data | Verbal(manufacturer's test pilot) |
| 19 | Fighter | Unsatisfactory | ------------ | |
| 20 | Fighter | Unsatisfactory | ------------ | |
| 21 | Fighter | Satisfactory | ------------ | |

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