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TESTS OF INVERTED SPINS IN THE NACA FREE-SPINNING TUNNELS

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NACA

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SUMMARY

Results are given of inverted-spin tests of 44 airplane models in the NACA 15-foot and 20-foot free-spinning tunnels. The data indicated that spins normally were steep and recovery by rudder reversal generally was rapid. Pulling the stick back diminished the tendency for the models to spin. Deflecting ailerons and rudder together tended to prevent the spin and crossing these controls tended to retard recovery.

INTRODUCTION

Inverted-spin tests of approximately 50 airplane models have been made over a period of several years in the NACA 15-foot and 20-foot free-spinning tunnels. The data for 44 of these models have been collected and are presented in the present report. A detailed analysis of the data is not made; however, several well-defined trends are pointed out. Special emphasis is given to the effects of aileron deflection on the recovery from the spin because relatively little attention has been given this aspect in reported flight tests of inverted spins (references 1 and 2).

MODELS

The type and mass characteristics of the airplanes for which model test results are presented are given in table I. The models represented conventional monoplanes with the exception of a biplane (N3N-3), a tailless airplane (XP-56), and a canard airplane (CW24-B). Because both single-engine and multiengine designs were tested, a wide range of mass distribution was covered.

The construction of spin models is described in detail in reference 3. The models, constructed principally of balsa, were ballasted for dynamic similarity to the corresponding airplane by the installation of proper weights at suitable locations. A remote-control mechanism served to move the rudder (or rudders) during the recovery tests. The maximum angular deflections of the controls used on each model were the same as for the airplane represented.

The models represented the airplanes in the normal loading condition. For the tests herein considered, the flaps were neutral and the landing gears were retracted except for the airplanes with nonretractable landing gear.

TESTING PROCEDURE

The testing procedures in both the NACA 15-foot and the NACA 20-foot free-spinning tunnels are essentially as described in reference 3. With the elevator and ailerons fixed in the desired positions and with the rudder (or rudders) set full with the desired spin, the model is launched by hand with an initial rotation in the direction of the spin. Recoveries are attempted by a rapid reversal of the rudder (or rudders) from full with the spin to full against the spin. Photographic observations are made during the steady spin of the acute angle α between the thrust axis and the vertical (approximately equal to the absolute value of the angle of attack at the plane of symmetry). Visual and photographic observations are also made of the number of turns for recovery N, which is defined as the number of turns the spinning model makes between the time the controls are moved and the time the spin rotation ceases.

PRECISION

The angle α can be measured within 1° and the number of recovery turns within 1/4 turn, except for certain cases in which the model is difficult to handle in the tunnel because of the wandering or oscillatory nature of the spin.

Comparison between model and airplane results for erect spins (reference 3) indicates that, because of scale and tunnel effects, lack of detail in the model, and differences in techniques, the spin-tunnel results are not always in complete agreement with results for the actual airplane. For a given loading condition and control setting, somewhat smaller angles of attack were generally obtained with the models than with the airplanes. A comparison of free-spinning wind-tunnel results with corresponding full-scale spin results (unpublished) showed that 80 percent of the model recovery tests predicted satisfactorily the recoveries of the corresponding airplanes and that 10 percent overestimated and 10 percent underestimated the number of turns required for recovery of the airplanes. Although most of the discrepancies have remained unexplained, it may be assumed that the agreement would be of the same order for inverted spins.

RESULTS AND DISCUSSION

The results of the inverted-spin tests are presented in table II, in which the control deflections are given in terms of rudder-pedal and stick displacements. In addition to the results for tests with the normal control configuration for spinning inverted - that is, one rudder pedal forward, the stick neutral laterally and forward longitudinally (rudder full with spin, ailerons neutral, and elevator up with respect to the ground) - results are also shown for tests made with various combinations of full lateral and longitudinal displacements of the control stick.

Effects of control position.- An examination of table II shows that approximately 20 percent of the models would not spin inverted with the normal control configuration for spinning inverted. The spins for all the models except one were steep (small α's) and recoveries were rapid. These results were obtained probably because, for a conventional tail layout, most of the vertical tail surface is not shielded by the tail plane when the model is spinning inverted and the tail damping-power factor (reference 4) is therefore relatively large. The values of this factor are given in table I and are considerably greater than the minimum design value of 0.000150 specified in reference 4. Moving the stick rearward - that is, moving the elevator down with respect to the ground - tended to prevent the inverted spin. This result tends to corroborate the statement made in reference 5 that, when an airplane is in an inverted spin, moving the stick rearward will generally cause recovery.

The lateral displacement of the stick also had a pronounced effect on the behavior of the models in inverted spins. Setting the controls together (fig. 1) – that is, stick right for a spin made with right rudder pedal forward (setting the ailerons against the rotation of the inverted model) – generally prevented the inverted spin regardless of the longitudinal location of the stick (elevator deflection). Crossing the controls – that is, stick left for a spin made with the right rudder pedal forward (putting the ailerons with the spinning rotation when inverted) – however, had the opposite effect, because spins could then be obtained with all models. These spins were somewhat flatter and had slower recoveries than spins with the stick neutral laterally, especially when the stick was also forward. With the stick left and forward and the right rudder pedal forward, recovery by rudder reversal alone was impossible in many cases.

Relation between mass distribution and effect of aileron deflection on spinning.– It was concluded in reference 6 that, for erect spins, the mass distribution of the airplane is a primary factor in determining the effect of aileron deflection; that is, for single-engine airplanes with the mass distributed mainly along the fuselage (moment of inertia about Y-axis I_Y appreciably greater than that about X-axis I_X), recovery was improved by setting the controls together (ailerons with the spinning rotation when erect). For multiengine airplanes or for the present-day single-engine airplanes with wing armament and wing fuel tanks (I_X greater than I_Y), however, crossing the controls (ailerons against the spinning rotation when erect) had a favorable effect on recovery.

Although the models tested in inverted spins covered a wide range of mass distribution, there was no point at which the effect of aileron deflection reversed. For all the models, setting the controls together was beneficial and crossing them was adverse. Although mass distribution is a prime factor in determining the effect of aileron deflection for erect spins, it appears to have, within the limits of present-day design, little influence on the effect of aileron deflection in the inverted spin.

APPLICATION TO FULL-SCALE SPINNING

Although the model test results generally indicated more rapid recovery from inverted than from erect spins,

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several considerations indicate that spinning airplanes inverted may be relatively hazardous. Some of the factors involved are

(1) Because of the high rate of descent indicated by the model test results, the control forces may be so high that the pilot cannot deflect the controls as desired.

(2) Violent oscillations of the airplane may confuse the pilot and prevent his making the desired control movements.

Because of these possible difficulties, precautions should be taken to enable the pilot to move the controls to the desired positions. The ability of the pilot to move the controls can be improved if properly adjusted safety belt, chest and shoulder harness, and toe straps are used.

CONCLUSIONS

Inverted-spin tests of 44 models in the NACA 15-foot and 20-foot free-spinning tunnels indicated the following conclusions:

1. The inverted spins were usually steep and therefore the rate of descent was relatively high. For the normal control position for spinning inverted (stick laterally neutral and longitudinally forward, rudder with the spin), recovery by reversal of the rudder alone generally was rapid.

2. Pulling the stick back diminished the tendency for the models to spin.

3. The aileron effect was quite marked. The results of the tests obtained with the models spinning inverted indicated that, within the range of mass distribution of present-day airplanes, setting the controls together (ailerons and rudder in the same direction) tended to prevent the inverted spin and crossing these controls retarded recovery from the inverted spin.

4. Because of practical factors, inverted spins may be hazardous and tests should be approached with caution.

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TABLE I.- DIMENSIONAL AND MASS CHARACTERISTICS OF AIRPLANES REPRESENTED BY MODELS

Airplane represented	Number of vertical tails	Number of wings	Vertical location of wing	Wing span (ft)	Tail damping-power factor when model is inverted (a)	Airplane mass (slugs)	Moments of inertia (slug-ft^2) I_X	I_Y	I_Z
XF2A-2	1	1	Mid	35	0.001042	166	2,110	3,410	5,080
F2A-1	1	1	Mid	35	.001042	158	2,095	3,440	5,130
[b]N3N-3	1	2	High-low	34	.000546	87	1,583	2,362	3,487
XF5F-1	2	1	Low	42	.000916	268	10,787	7,174	17,264
XFL-1	1	1	Low	35	.000499	193	2,750	4,560	6,890
XP-40	1	1	Low	37.29	.001043	212	2,172	6,744	8,602
XSB2A-1	1	1	Mid	47	.000812	315	10,204	17,714	27,019
XSB2C-1	1	1	Mid	50	.000600	316	8,150	13,475	20,470
XBT-12	1	1	Low	40.03	.000865	133	2,492	4,170	6,293
SBD-1	1	1	Low	41.51	.001442	236	4,841	8,692	12,544
B-26	1	1	High	65	.001055	826	63,651	69,798	129,371
A-20	1	1	High	61.33	.001852	592	33,706	24,557	55,287
XBT-13	1	1	Low	42	.000935	131	2,659	4,122	6,201
XBT-11	1	1	Low	42	.000508	137	2,700	4,360	5,900
O-52	1	1	High	40.79	.001169	158	3,705	4,970	7,580
XP-46	1	1	Low	34.33	.000924	210	3,285	5,540	8,550
XP-50	2	1	Low	42	.001218	324	13,793	7,582	21,210
P-44	1	1	Low	38	.001710	270	4,903	8,130	11,819
XP-56	C	1	Mid	40.59	------	316	9,313	6,834	15,635
XTBU-1	1	1	Mid	57.18	.000995	410	12,543	23,969	34,911
XTBF-1	1	1	Mid	54.17	.000379	411	11,784	21,156	31,183
YP-43	1	1	Low	36	.001680	214	3,439	5,769	8,557
XP-47B	1	1	Low	40.78	.001835	369	13,867	13,047	25,841
BT-14	1	1	Low	41.02	.000649	139	2,741	4,237	5,681
XP-60	1	1	Low	41.44	.000627	288	8,920	9,181	17,224
XP-61	2	1	Mid	66	.000962	800	53,494	35,082	83,423
XAT-15	1	1	High	59.68	.001636	379	20,370	19,934	37,736
XP-59	2	1	Mid	40	.003780	348	6,330	8,320	14,000
P-39D	1	1	Low	34	.001151	230	5,201	6,077	10,704
XAT-13	2	1	Mid	52.5	.001166	328	15,600	11,016	25,183
CW24-B	2	1	Low	36.58	.000092	101	1,410	4,062	5,042
DC-3	1	1	Low	95	.001301	795	66,668	91,690	150,420
XP-63	1	1	Low	38.33	.001328	231	6,340	7,642	13,202
XP-67	1	1	Mid	55	.001116	629	41,989	25,596	63,625
P-40E	1	1	Low	37.29	.000958	266	5,430	7,827	12,505
P-40F	1	1	Low	37.29	.000958	264	5,029	7,899	12,146
XSB3C-1	1	1	Low	51.95	.001052	436	16,100	20,800	35,200
XP-69	1	1	Mid	52	.001910	559	26,446	49,174	73,746
SNC-1	1	1	Low	35	.002150	113	1,242	2,863	3,937
XP-62	1	1	Low	53.65	.000706	452	13,241	22,545	33,714
XF6F-3	1	1	Mid	42.83	.000878	344	8,787	11,563	19,950
XSB2D-1	1	1	Mid	45	.002180	454	13,934	25,533	37,832
XP-60A	1	1	Low	41.31	.001367	294	7,931	10,690	17,636
XF14C-1	1	1	Low	45.6	.000965	396	11,713	14,743	24,338

[a]Tail damping-power factor is defined in reference 4.
[b]Data presented are for landplane version.

TABLE II.- EFFECT OF AILERON AND ELEVATOR DEFLECTIONS ON ANGLE OF ATTACK α OF, AND TURNS FOR RECOVERY N FROM, INVERTED SPINS

[Angle of attack given for rudder with spins; recovery attempted by rapid full rudder reversal]

Airplane represented	Stick and rudder together (ailerons against inverted spin)						Stick neutral laterally (ailerons neutral)						Stick and rudder crossed (ailerons with inverted spin)					
	Stick forward		Stick neutral		Stick back		Stick forward		Stick neutral		Stick back		Stick forward		Stick neutral		Stick back	
	α (deg)	N (turns)	α (deg)	N (turns)	α (deg)	N (turns)	α (deg)	N (turns)	α (deg)	N (turns)	α (deg)	N (turns)	α (deg)	N (turns)	α (deg)	N (turns)	α (deg)	N (turns)
XF2A-2	---	----	[a]NO		---	----	(b)	1/4	---	1/4	(b)	1/4	---	----	---	1/2	---	----
F2A-1	---	----	---	----	NO		(b)	----	NO		NO		(b)	1	---	----	NO	
[c]N3N-3	NO		NO		NO		32	1/4	NO		NO		50	1/2	43	1/2	NO	
XF5F-1	NO		NO		NO		NO		NO		NO		---	[d]2	---	2	NO	
XFL-1	---	----	---	----	(b)	----	---	$1\frac{1}{2}$	---	----	---	1	---	1/4	---	----	---	1
XP-40	(b)	----	(b)	----	(b)	----	(b)	----	(b)	----	---	1/4	(b)	----	---	1/4	---	1/2
XSB2A-1	NO		NO		NO		---	1/2	NO		NO		---	1/2	(b)	----	NO	
XSB2C-1	NO		NO		NO		(b)	----	NO		NO		---	----	---	----	---	1/2
XBT-12	NO		NO		NO		NO		NO		NO		50	----	NO		NO	
SBD-1	NO		NO		NO		NO		NO		NO		(b)	----	NO		NO	
B-26	NO		---	----	---	----	38	----	---	----	32	----	48	----	---	----	---	----
A-20	NO		NO		NO		(b)	----	NO		NO		(b)	----	(b)	----	(b)	----
XBT-13	NO		NO		NO		NO		NO		NO		32	----	NO		NO	
XBT-11	NO		NO		NO		29	1/2	NO		NO		52	[d]$5\frac{1}{2}$	44	$1\frac{1}{4}$	31	1
O-52	NO		NO		NO		(b)	----	NO		NO		39	----	NO		NO	
XP-46	NO		NO		36	3/4	(b)	----	(b)	----	44	3/4	38	$1\frac{1}{2}$	44	1	27	3/4
XP-50	---	----	---	----	NO		NO		NO		---	----	(e)	[d]2	NO		---	----
P-44	NO		NO		NO		NO		NO		NO		43	----	40	----	31	----
XP-56	NO		NO		76	----	47	[d]3	42	[d]3	52	2	70	[f]∞	55	∞	---	----
XTBU-1	NO		NO		NO		33	1/2	NO		NO		37	3/4	32	3/4	NO	
XTBF-1	NO		NO		NO		(b)	----	NO		NO		[illegible]	1	(b)	----	NO	
YP-43	---	----	---	----	NO		(b)	----	(b)	----	(b)	----	(e)	----	35	1/4	30	1/4
XP-47B	NO		NO		NO		(b)	----	(b)	----	NO		43	$1\frac{3}{4}$	40	3/4	(b)	----
BT-14	NO		NO		NO		(b)	----	NO		NO		29	[d]$3\frac{1}{2}$	22	3/4	NO	
XP-60	NO		NO		NO		---	1/2	---	3/4	---	1/2	---	$1\frac{3}{4}$	47	$2\frac{1}{2}$	---	$2\frac{1}{4}$
XP-61	NO		NO		NO		38	1/2	NO		NO		35	$1\frac{1}{4}$	NO		NO	
XAT-15	NO		---	----	---	----	44	3/4	NO		---	----	50	1	37	3/4	NO	
XP-59	NO		NO		NO		NO		NO		NO		(b)	----	NO		NO	
P-39D	(b)	1/4	---	----	(b)	----	---	3/4	---	----	---	$1\frac{1}{4}$	---	$1\frac{1}{2}$	---	----	---	$1\frac{1}{2}$
XAT-13	---	----	---	----	---	----	NO		NO		---	----	51	3/4	39	$1\frac{1}{4}$	NO	
CW24-B	NO		NO		NO		NO		85	1/2	82	1/2	NO		NO		NO	
DC-3	---	----	---	----	---	----	NO		NO		NO		---	----	---	----	---	----
XP-63	---	----	---	----	---	----	---	----	NO		---	----	---		---	----	---	1
XP-67	NO		NO		NO		31	1	NO		NO		41	[d]$2\frac{1}{2}$	40	$1\frac{1}{4}$	37	$1\frac{1}{4}$
P-40E	NO		NO		NO		45	3/4	---	----	---	----	40	1	31	3/4	33	1
P-40F	27	1/2	---	----	28	1/2	29	1/2	---	----	---	----	32	----	---	----	26	1/4
XSB3C-1	NO		NO		NO		NO		39	3/4	NO		48	1	44	1	NO	
XP-69	NO		NO		NO		---	1/2	NO		---	----	---	----	---	1/2	---	----
SNC-1	NO		NO		NO		(b)	1/4	NO		NO		42	[d]$4\frac{1}{4}$	36	$1\frac{1}{4}$	24	1/2
XP-62	NO		NO		NO		31	1/2	34	1/2	30	1/2	49	$1\frac{1}{2}$	46	$1\frac{1}{4}$	32	1
XF6F-3	(b)	----	NO		NO		43	$1\frac{3}{4}$	41	----	NO		52	[d]2	44	----	34	----
XSB2D-1	NO		NO		NO		28	----	NO		NO		33	$1\frac{1}{4}$	28	1	26	3/4
XP-60A	NO		NO		NO		34	1/4	35	1/2	NO		51	1	43	1	34	1
XF14C-1	NO		---	----	NO		33	1/2	NO		NO		41	[d]3	33	$1\frac{3}{4}$	31	$1\frac{3}{4}$

[a]NO indicates the model would not spin.
[b]Steep spin.
[c]Results presented for landplane version.
[d]Model had not recovered in number of turns indicated.
[e]Spin at moderate angle of attack.
[f]Model would not recover indicated by ∞.

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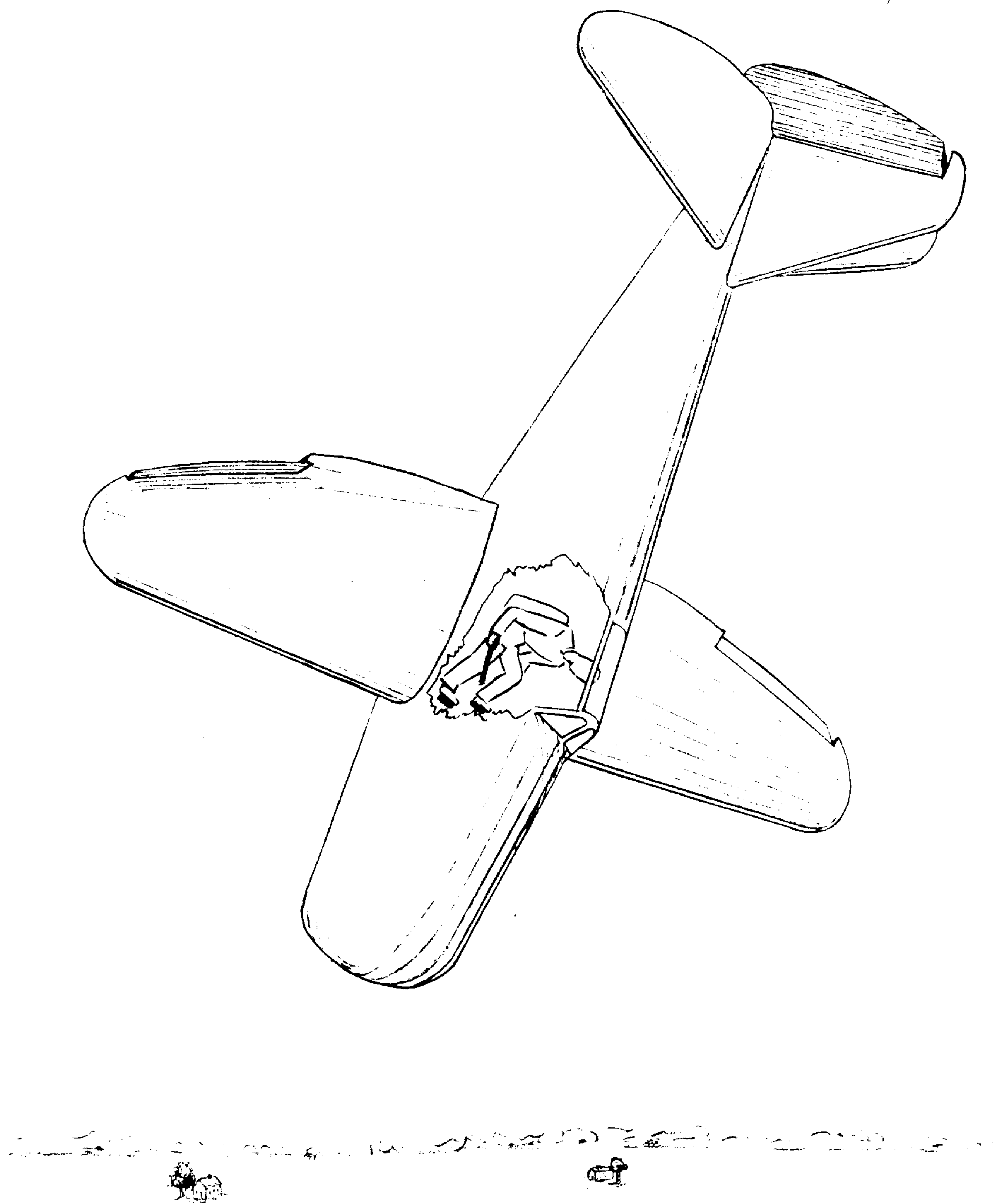

Figure 1.- Stick and rudder pedal together in an inverted spin.