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A Criterion for the Prediction of the Recovery Characteristics of Spinning Aircraft

By

T. H. Kerr, B.Sc.

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A Criterion for the prediotion of the Recovery Characteristics of Spinning Aircraft

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SUMMARY

In an attempt to establish a simple criterion for the prediction of the spin and recovery characteristics of aircraft, it has been deduced that the two most important parameters are the unbalanced rolling moment coefficient about the wind axis in the spin and the ratio of pitching to rolling moment of inertia. Using the results of full scale spinning tests on thirty-three aircraft, it has been possible to establish empirical relationships between the estimated unbalanced rolling moment coefficient and the inertia ratio which effectively divide the aircraft into the three groups which have satisfactory, borderline and unsatisfactory recovery characteristics.

A simple method is presented for estimating the unbalanced rolling moment coefficient knowing only the shape of the aircraft. With this information and a knowledge of the mass distribution of the aircraft, the empirical relationships should give a good indication of the spin recovery characteristics on new designs. This method is expected to be of particular value to aircraft designers in the early design stages since the method does not depend on the result, of tunnel tests.

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1 Introduction

The aim of research into the spin and recovery characteristics of aircraft must be to enable the accurate prediction of these characteristics in future designs. The method, present and past, is to build a scale model to absolute dynamic similarity and complete a series of spinning tests in the Vertical Tunnel. After making an allowance for the difference in Reynolds number between the model and Pull scale aircraft, the full scale characteristics of the spin are predicted directly from the model tests. These tests are not done until the design of the aircraft is almost settled and it is, therefore, very important that the designer should have some guide, as to the probable characteristics of the aircraft in the spin and during the recovery, in the early stages of the design. This is particularly important for elementary end advanced trainers as a satisfactory spin and a high standard of recovery is required of these types.

Two methods of producing such a prediction can be mentioned:-

(i) Calculations on the detailed design of each type based on the aerodynamic derivatives obtaineu from rolling balance tests. To be effective, the data used in this method must be obtained at or near flight Reynolds numbers and this will not be possible until the rolling balance in the Bedford tunnel is in use.

(ii) A simple criterion based on the geometry of the aircraft and compared. with the wealth of flight experience which is available. A criterion of this type is of a limited character and at best can only be treated as approximate for borderline cases but it may prove to be a valuable guide to designers in the oases of the elementary and advanced trainers.

Several attempts have been made in the past to produce criteria of this type (ii) and these are discussed in the next section.

2 Previous Criteria

The first attempt to produce a criterion was made by Finn in 1937[1]. He recognised that the failure of models to pass the model spinning test requirements was usually due to one or more of the following:-

(i) a large distribution of mass along the X-axis i.e. (C - A) large; this has subsequently been shown to apply to model scale only and the opposite is true full scale,

(ii) inefficient body section i.e. the body cross-section of a type which produces a low damping due to rotation,

(iii) deficiency in side area - again producing low body damping,

(iv) shielding of the rudder by the tailplane.

During spinning tests in the Vertical tunnel most models spin with the wings approximately horizontal and therefore the inertia difference (A - B) was not important.

As far as the inertia loading of the aircraft was concerned (C - A) was regarded as being the most important parameter and therefore the inertia difference coefficient $\dfrac{(C - A)}{\rho S \left(\dfrac{b}{2}\right)^3}$ was taken as an independent variable throughout. This parameter has a direct effect on λ and therefore also indirectly affects the body damping.

The body damping or the resistance offered by fuselages of similar cross-section to rotation in the spin may be expected. to vary as $\Sigma x^2 A$ where x is the distance of an element of side area A from the C.G. In order to compare the various designs the body damping ratio was written in the form $\dfrac{\Sigma x^2 A}{S\left(\frac{b}{2}\right)^2}$. The areas of fin and rudder shielded by the tailplane and elevator, in a spin at 45° incidence assuming a wake spread of 30°, were assumed to have zero damping and were therefore ignored. The area under the tailplane ad elevator was more effective due to the tailplane position above it and a factor of two was applied to this area.

Although it was realised that body cross-section affected the body damping no allowance was made for this in the analysis.

The effectiveness of the rudder as a recovery control was assumed to be proportional to the unshielded rudder area ad was expressed in the form

$$\text{Unshielded Rudder Volume Coefficient} = \frac{\text{unshielded rudder area} \times \text{distance from C.G.}}{S\,\frac{b}{2}}$$

The two aerodynamic criteria developed i.e. the body damping ratio end the unshielded rudder volume coefficient, were plotted against the inertia term $\dfrac{O - A}{\rho\, S\left(\frac{b}{2}\right)^3}$. A rough separation between passes and fails was obtained using firstly, the two coefficients separately and secondly, the coefficients multiplied together to form 'the damping power factor'. The second case gave better separation between the passes and failures to pass the required recovery standards.

This criterion was modified by Tye ad Fagg[2] in their extension of the enquiry, to include full scale spinning aircraft.

The changes they made were:-

(i) The body damping ooeffioient was expressed in the form

$$\int_{-\ell_1}^{\ell_2} \frac{\varepsilon\, h x^2\, dx}{S\, b^2}$$

where h is the depth of the body (side view)

x is the distance measured along the body axis from the C.G.

ε is the weighting factor applied. to various parts of side area

ℓ_1 maximum -ve value of x

ℓ_2 maximum +ve value of x.

The factor ε was given values

2 for fuselage and fin under tailplane
1.5 for rudder under tailplane
-0.25 for shielded rudder and fin
1.0 for remaining side area.

(ii) The unshielded rudder volume coefficient is now defined as

$$\frac{A_R \ell}{Sb}$$

where A_R is the unshielded rudder area.

This analysis indicated the minimum degree of body damping and unshielded rudder volume coefficient which the designer should aim to provide but compliance with the criterion did not guarantee good spinning qualities full scale as factors such as body section and inertia yawing moment couples had been ignored.

A more complete analysis was offered by Pringle and Harper[3] in March 1952. Taken as a whole, this analysis represented a very large step forward. over the work of its predecessors. An effort was made to present the basic causes of error in previous criteria. Moreover, it was devoted entirely to the analysis of full scale recovery predictions. The criterion suggested depended upon the equation for the equilibrium of yawing moments (body axis) in the spin.

Unshielded rudder volume coefficient + body damping coefficient + inertia yawing moment + inferred wing yawing moment coefficient = 0.

Of these quantities only the inferred wing yawing moment cannot be calculated and therefore for the borderline case the inferred wing yawing moment was assumed to be equal to and of opposite sign to the sum of the other three quantities.

Another assumption was that the wing yawing moment was proportional to the thickness/chord ratio and over a wide range of λ was assumed independent of λ.

The diagram showing the plotted results (Fig.2) of inferred wing yawing moment against thickness/chord ratio for thirty-one aircraft show that in general a separation, between aircraft which recover from the spin by normal control movements and those which fail, is reasonably defined.

The method of calculation of the body damping coefficient, unshielded rudder volume coefficient and inertia yawing moment couple are repeated below.

The body damping coefficient is equal to

$$\frac{\varepsilon\lambda}{Sb^2} \int h\, x^2\, dx$$

The weighting-factor ε is given values at an incidence of 45° in Table I below.

TABLE I

Effect of Body Section on Damping in Roll

Body Cross-Section	ε at $\alpha = 45^{\circ}$
Circular (pointed profile)	+0.6
Rectangular	+1.5
Elliptical	+2.1
Round top, flat bottom	+1.1
Round top, flat bottom + strakes	+1.7*
Round bottom, flat top	+2.5
Round bottom, flat top + strakes	+3.5*
Fin: Free	+1.5
Fin: Under tailplane	+3.0
Fin: Above tailplane	-0.4
Rudder under tailplane	+2

*Depending on width of strakes. This is for 0.014 ℓ'' where ℓ'' is distance of C.G. to rudder post.

The inclusion of λ in the body damping coefficient in this form was demonstrated by Irving and Batson[4]. Their results showed that the body damping coefficient was almost directly proportional to λ over a range of λ from 0 to 0.9.

No changes were made to the unshielded rudder volume coefficient but it is worth noting that this has been demonstrated to be independent of λ at a given incidence again by Irving and Batson[5].

The inertia yawing couple $\overline{n'_I}$ was also included. in the analysis. This was estimated from the particular values of (A - B) for the aircraft and assumed values of ℓ'_p, ℓ_v and C_L in the spin. The method is shown in Ref.3 and in this way, a guess at the inertia couple could be made. Calculations over a range of types shows that this may have a value of ±5 units.

3 Recent Evidence

3.1 Full Scale Tests

The results of some recent full scale tests on a Meteor 8[6] with five different inertia ratios of the pitching to rolling moment of inertia are shown in Figs.3 and 4.

The technique of the tests was to apply 'outboard' or pro-spin engine at the stall and maintain the engine thrust throughout the spin and recovery. The thrust of the pro-spin engine was measured during the spin and recovery and in the lower graphs (Fig.3) the time required to recover is plotted against the yawing moment applied by the pro-spin engine. The recovery action taken by the pilot was either, full opposite rudder and the elevator moved down until the spin stops (normal recovery action) or full opposite rudder with elevator remaining fully up until the spin stops (rudder only recoveries). In both cases the ailerons were maintained neutral.

	Aircraft	Weight	A	B	C	b	S	μ	λ	$\frac{B}{A}$	$\frac{t}{c}$	P, B or F*	$\frac{A_R \ell}{S_b} \times 10^3$	$\overline{\ell p_B} \times 10^3$	$\overline{\ell p_W} \times 10^3$	Unbalanced Anti-spin Rolling Moment Coefficient $\times 10^3$ Wind Axes
1	Oxford	7,196	322,550	193,400	475,000	53.33	348	25.6	0.575	0.606	0.12	B	8.8	14.2	-18.2	4.8
												F	3.3	14.7	-18.2	-0.2
2	Skua					46	318	33.9	0.433	2.3	0.143	B	15	11	-16.4	9.6
3	Martin Baker F5/34	4,730	105,800	152,400	224,000	42.48	216.4	21.35	0.418	1.44	0.152	U	18.2	49.8	-16.7	41.3
4	Hurricane					40	231.5		0.39	1.37	0.158	P	11.6	22.4	-16.4	17.6
									0.368			F	8.8	19.7	-16.4	12.1
5	Jockey															
6	Spitfire	4,900	106,200	119,000	219,000	37.12	219.6	25.1	0.352	1.120	0.103	P	6.2	19.3	-9.2	16.3
7	Nighthawk									1.39	0.146	F			-17.2	5.8
8	Master											P				
9	Wellesley									0.52			3.6	17.4		27.2
10	P & P M 18	1,785	18,690	35,420	54,550	30.94	183	26.8	0.474	1.898	0.174	F	5.0	7.5	-21.2	-8.7
11	Magister	1,835	26,750	42,450	64,000	33.8	179	13.25	0.450	1.55	0.145	P	12.9	16.1	-17.3	11.7
									0.458			F	10.3	10.7	-17.3	3.7
12	Mentor	2,525	34,780	48,150	78,550	35	180	16.83	0.448	1.39	0.145	P	10.3	19.5	-17.2	12.6
13	Harvard	5,308	110,800	162,000	248,000	42.02	253.7	20.7		1.465	0.135	B			-12	5.5
14	Defiant												12.3	21.7		
15	Moth Minor															
16	Typhoon	11,017	294,500	199,500	461,000	41.58	279	63.7	0.388	0.627	0.164	B	12.8	19.2	-16.7	15.3
17	Bristol 133															
18	Proctor	3,250	74,300	54,900	121,100	39.5	202	26.9	0.517	0.739	0.160	F	8.1	8.4	-22	-5.5
19	P & P M 20/2	7,342	209,300	204,600	379,000	34.55	236	59.5	0.296	0.979	0.170	P				
											0.170	B				
											0.170	F				
20	P & P M 28															
21	Mosquito	19,000				54.2	450		0.384	0.790	0.120	B	8	12	-12.3	7.7
22	Vickers F7/41	15,324	1,352,000	745,000	2,074,000	56.9	435	41	0.342	0.56	0.130	F				
23	Seafire															
24	Prentice	3,850	35,000	33,200	62,100	46	305	18.2	1.109	0.949	0.135	P	8	17	-21.6	3.4
												F	8	14.5	-21.6	0.9
25	Meteor 4	13,300	427,000	419,500	889,000	44.33	387	51.4	0.23	0.981	0.105	P	17	29.5	-6.5	40
26	Cornell	2,760	10,720	18,760	22,370	36	200	25.3	0.31	1.75	0.125	P			-11.0	17.5
27	Attacker	11,300	227,000	585,000	754,000	37.04		56.4	0.162	2.58	0.1075	P	6.5	9.5	-4.5	11.5
28	Wyvern	16,555	505,000	975,000	1,390,000	44		43.8	0.238	1.93	0.130	P	1.8	19.2	-8.2	12.8
29	Meteor 4		421,000	654,000	1,090,000			40.4	0.23	1.55	0.105	P	17	30.0	-6.4	40.6
30a	Meteor 8	15,390	438,000	708,000	1,088,000	37.16	350	50	0.233	1.62	0.105	P	10	29	-6.5	32.5
30b	Meteor 8	16,864	438,000	973,500	1,353,500	37.16	350	55	0.189	2.23	0.105	P	10	23	-5.25	27.7
30c	Meteor 8	15,894	634,000	708,000	1,284,000	37.16	350	52	0.233	1.12	0.105	P	10	28	-6.5	31.5
31	Venom	12,640	883,620	306,830	1,170,150	40		33.8	0.3	0.346		P	0	8.90	-7.1	1.8
31	Venom	9,379	212,140	285,360	479,600	40			0.31	1.34		P	0	10	-7.1	2.9
32a	PN7/46	11,650	222,000	438,000	635,000	36.5	268	49.5	0.22	2	0.10	P	12.3	12.3	-5.8	18.8
32b	N7/46	13,050	173,500	547,000	685,000	39	278			3.14	0.10	P	12.3	11.7	-5.3	18.7
33	Provost	3,894	62,722	125,447	175,568	35.2		14.04	0.32	2	0.135	P	7.1	27.8	-11.5	23.4
34	Fiat G.49	6,140	146,200	181,000	314,000	42.7	242		0.345	1.25	0.13	F	1.0	3.7	-12.0	-7.3
A	Swift											P				12.9
B	Sabre											P				8.4
C	Hunter											Not yet had full scale spinning trials				11.5

*Full scale pass (P), borderline (B) or Fail (F)

These results show that the inertia loading of the aircraft made a large difference to the standard of recovery. The mean slope of the curve (Fig.4) is negative and gives a greatly improved recovery standard as the pitching to rolling moment of inertia was increases.

The recovery standard of the Meteor 8 for three inertia conditions is plotted in Fig.2 (Aircraft 30a, b and c where B/A = 1.62, 2.23 and 1.12 respectively) and by this criterion the standard of recovery should be reduced and not increased with B/A as the full scale results indicate.

3.2 Calculations based on Tunnel Rolling Balance Tests

A series of wind tunnel tests on a rectangular Clarke Y wing were made with the NACA spinning balance by Bamber and Zimmerman[7] as part of a research on spinning aircraft. All six components of aerodynamic force and moments were measured through a range of angles of attack, angles of sideslip, and values of $\frac{\Omega b}{2V}$ likely to be obtained by spinning aircraft. The latter part of the report contains an analysis, using this data, for estimating the spinning characteristics of an aircraft. The most interesting result, when these measurements are used in calculations with wing loadings and inertia ratio common today, is shown in Fig.5.

The quantities plotted are the yawing moment (anti-spin) which must be supplied by parts of the aircraft other than the wing for equilibrium in the spin against the ratio of the pitching to rolling moment of inertia parameter for incidences of 30 and 45°. This result again shows how the equilibrium in the spin and therefore the recovery standard depends upon the inertia loading of the aircraft. Other crossplotted results from this report showed that the wing rolling moments in the spin are almost directly proportional to $\lambda\left(\frac{\Omega b}{2V}\right)$. Calculations using strip theory on wings at high Reynolds numbers confirm this result up to $\lambda \simeq 0.5$ or 0.6.

Much time and effort in the past has been devoted to showing that the pro-spin wing moments depend upon the thickness/chord ratio of the wing and rolling balance tests have shown this to be true. In view of these previous results, a graph of the suggested wing rolling moments is shown in Fig.6 based on the assumption that the wing rolling moments are a linear function of thickness chord ratio.

4 The Criterion

4.1 Fundamentals of the Analysis

On examining the equilibrium of an aircraft in the spin one can consider either the equilibrium between the inertia and aerodynamic forces about the wind axes or about aircraft body axes. If aircraft body axes are chosen then there is equilibrium between the inertia and aerodynamic couples about each axis and any small change about one axis will affect the equilibrium about the other two.

If aircraft wind axes are chosen then since the centrifugal forces on all parts of the aircraft act radially from the axis of the spin, there can be no centrifugal couple about that axis and therefore the equilibrium of the spin is entirely aerodynamic in nature. Thus, for equilibrium in the spin the pro-spin moment due to the wings must equal the anti-spin moments due to other parts of the aircraft in the spin.

$$\therefore \overline{\ell p_B} + \overline{\ell \zeta} + \overline{\ell p_W} = 0 \qquad \text{(wind axis)}$$

If the rudder is central and the aircraft is in equilibrium then

$$\overline{\ell p_B} + \overline{\ell p_W} = 0.$$

This does not represent the complete picture of the equilibrium in the spin as each of the inertia couples about body axis must be balanced by corresponding aerodynamic couples. These can exert a marked influence over the equilibrium of the spin and the recovery.

The influence of the pitching moments of inertia is greatest in deciding the rate of rotation about the spin axis for equilibrium at a given incidence. This is reflected in the equation for deriving $\lambda\left(\frac{\Omega b}{2V}\right)$ for the aircraft.

The rolling and yawing inertia couples Influence the angle of tilt of the wings and thus the sideslip in the spin. Their influence on the spin and recovery characteristics of an aircraft ore shown in Figs.3, 4 and 5 and the important parameter appears to be the ratio of the yawing and rolling inertia couples which can be expressed in the form.

$$\frac{\dfrac{A - B}{\rho S \left(\frac{b}{2}\right)^3}}{\dfrac{C - B}{\rho S \left(\frac{b}{2}\right)^3}} = \frac{A - B}{C - B} \simeq \frac{A - B}{A} = 1 - \frac{B}{A}$$

as $A+B \simeq C$.

Therefore the two most important parameters am:-

(i) $\overline{\ell p_B} + \overline{\ell \zeta} + \overline{\ell p_W}$

and (ii) $\left(1 - \frac{B}{A}\right)$.

For the recovery from the spin when the rudder is deflected against the spin if

$$\overline{\ell p_B} + \overline{\ell \zeta} + \overline{\ell p_W} = 0$$

then theoretically we have the case of a borderline aircraft which just does not recover from the spin. If these do not equal zero, then we have an unbalanced rolling moment coefficient (URMC) about the wind axis and if this is anti-spin or positive then the aircraft should recover from the spin. The results of calculations of this type are plotted (Figs.7 and 8) for approximately 25 aircraft. Boundaries can then be drawn in separating the aircraft which were pass, borderline, or fail in their full scale spinning tests.

Thus to assess a new aircraft the calculation of the two important parameters should be male and the recovery characteristics assessed by comparison with the empirical boundaries which have been drawn on Figs.7 and 8.

In a calculation of this type it is Important to keep it as simple as possible and only cne spinning incidence is used to assess the characteristics of the spin. This is 45^{o} at the plane of symmetry as

(i) this is a mean spinning incidence of an average aircraft,

(ii) the rate of rotation about the axis of the spin will be a minimum and is the worst case when body damping is considered.

4.2 The Criterion

The criterion given below is based broadly upon previous criteria with modifications to the methods of assessing the results.

The method of application should be as follows:-

(a) to estimate λ from the general layout and loading of the aircraft

$$\lambda = \sqrt{\frac{1.3}{A\!\!R\ b_1}}$$

where $A\!\!R$ is the aspect ratio

$$b_1 = \frac{(C - A)}{g \rho S \left(\frac{b}{2}\right)^3}$$

(b) To calculate the anti-spin rolling moment coefficient (wind axis) due to the body at a mean incidence of 45^{o}.

Values of ε can be obtained from Table I and Fig.1 and assuming a wake spread over the tailplane of 30^{o}. It is usually impossible to allocate one value of ε for a complete fuselage and it is, therefore, essential to allocate, a particular value of ε for each section of the fuselage as the calculation is made.

$$\overline{\ell p_B} = A \int \frac{\varepsilon\ h\ x^2\ dx}{Sb^2}$$

(c) . To calculate the anti-spin moment due to the movement of the rudder from neutral to fully anti-spin.

$$\overline{\ell \zeta} = \frac{A_R \ell}{Sb} \qquad \text{(Fig.1)}$$

(d) To estimate the wing rolling moment coefficient from Fig.6.

(e) Obtain the unbalanced (anti-spin) rolling moment coefficient from the equation

$$\text{URMC} = \overline{\ell\zeta} + \overline{\ell p_B} + \overline{\ell p_W}$$

(f) Plot this result against $\left(1 - \frac{B}{A}\right)$ and assess whether the aircraft is likely to have a satisfactory spin recovery characteristic by reference to the empirical boundaries which have been drawn on Figs.7 and 8.

5 Discussion

A critical examination of Fig.7 will show both the weaknesses and advantages of this criterion over previous attempts.

(i) Although a good deal of effort has been applied, no evidence has been found to show that the Hurricane (Aircraft 4) was a fail[3] and a fairer classification is thought to be borderline. It was classified in this way in Fig.7.

(ii) The criterion does not appear to apply to aircraft of the Vampire-Venom type (Aircraft 31). Allocation of values of ε in the formulae for body damping $\overline{\ell p_B}$ do not appear to represent a true case even when the side area is multiplied by 2 to represent the damping over the twin booms.

(iii) There is a considerable amount of scatter for aircraft which have positive values of $\left(1 - \frac{B}{A}\right)$.

It is important to note that the criteria takes account of rudder power alone as a recovery control but in flight the normal recovery action *is* to use opposite rudder and to move the elevator down. As the value of $\frac{B}{A}$ decreases the elevator becomes increasingly important as a recovery control as can be seen if Fig.3 is examined. The Value of the elevator as a recovery control is extremely difficult to assess as it depends upon

(1) the effectiveness of the rudder in reducing the rate of rotation in the spin

and (2) the effeot *on* the rudder of applying down elevator during the recovery. This can be extremely important if, when applying down elevator during a recovery the shielded area of the fin and rudder is increased. This could have a very *serious* adverse effect.

Thus the scatter shown when $\left(1 - \frac{B}{A}\right)$ is positive probably depends upon the effect of applying down elevator during the recovery from the spin.

A word of warning might be offered to designers here, as it is dangerous to rely on elevator power for the recovery from the spin. At best it leads to long recovery times with high rates of roll during the recovery which cause stressing difficulties in the wings and possible disorientation of the pilot during the recoveries.

(iv) The criterion shows an improving recovery standard as the pitching moment of inertia of the aircraft is increased. This agrees with recent full scale experience (Aircraft 30a, b, c) and the calculations based on tunnel tests.

This is the most important improvement over previous criteria which have always shown a decrease in recovery standard as the pitching moment of inertia has been increase&.

(v) The criterion includes an estimate of the wing rolling moment (wind axis) and when more data becomes available it can be applied with only slight modification to the criterion for both straight and swept wing aircraft. A summary of present data for swept wing aircraft is discussed in the next section.

6 Extension to Swept Wing Aircraft

The calculation of unshielded rudder area and body damping coefficient will be modified in that allowance must be made for the sweepback of the tailplane. It is suggested that the present AP.970 recommendations be continued and 30 and 60° lines for estimating the shielded fin and rudder area be drawn from a point one third of the span from the fuselage side.

Very little is known of the rolling moments of swept wings at spinning incidences but recent full scale experience shows that at low values of λ (less than 0.2) the spin is little different from that of similar straight wing aircraft. As a result of this it is suggested that the same estimated wing rolling moment coefficients be used although comparison of the $C_L - \alpha$ curves indicate that the results given by this criterion are likely to be a little pessimistic. Fig.9 shows the results for three swept wing aircraft plotted on a graph which includes the boundary for passes and fails on straight wing aircraft.

7 Conclusions

(1) The limitations of a criterion of this type cannot be over emphasised particularly in borderline cases but it is hoped that it will prove a valuable guide to designers, particularly in the cases of elementary and advanced trainers.

(ii) The results (Figs.7 and 8) do separate aircraft into three classes, pass, borderline and fail for the recovery from the spin.

(iii) The principal advantage of the new criterion is that it includes the important parameter $\frac{B}{A}$ and indicates that the recovery standards will improve as $\frac{B}{A}$ increases. This is in agreement with the results of some American rolling balance tests and recent full scale experience.

(iv) Although the elevator, as a recovery control, is not included in the criterion, its importance has been emphasised in the diagrams and calculations.

(v) As soon as the results from the Bedford tunnel rolling balance tests are available, the methods of extracting the wing rolling moments, body damping and rudder power should be revised taking advantage of these results

LIST OF SYMBOLS

x	distance of element of side area from C.G.
A	area of element of side area $= h\,dx$
S	wing area
b	wing span
A_R	unshielded. rudder area
h	depth of fuselage
ℓ_1	maximum negative value of x
ℓ_2	maximum positive value of x
ℓ	distance of centeroid of the unshielded rudder area from C.G.
ε	weighting factor applied to various parts of side area

$$\lambda = \frac{\Omega b}{2V} \qquad \mu_1 = \frac{C' - A}{g\rho S\left(\frac{b}{2}\right)^3}$$

Ω	rate of rotation about spin axis	
V	true rate of descent ft/sec	
$\overline{\ell p_B}$	body damping coefficient	wind axes
$\overline{\ell p_W}$	wing rolling moment coefficient	wind axes
$\overline{\ell_\zeta}$	unshielded rudder volume coefficient when the rudder is deflected against the spin	wind axes
A	rolling moment of inertia	lb.ft^2
B	pitching moment of inertia	lb.ft^2
C	yawing moment of inertia	lb.ft^2
ρ	density at altitude considered slgs.ft^2	

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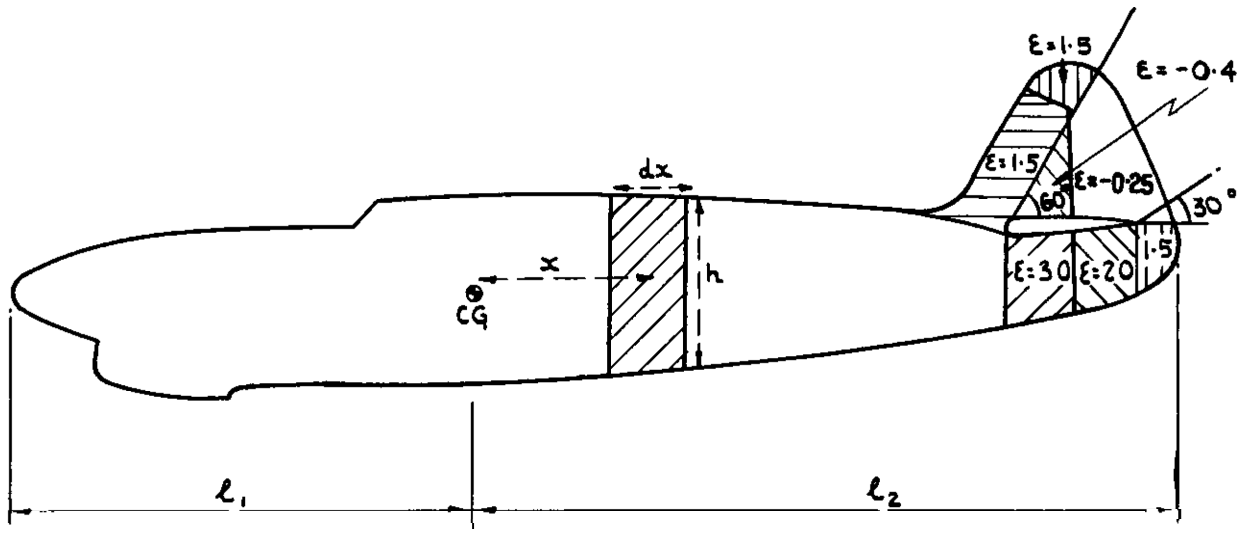
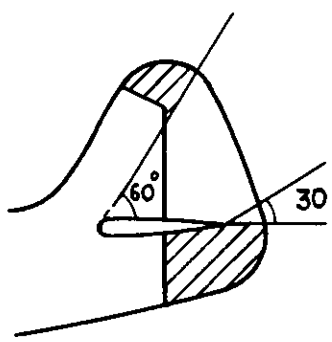
4	H.B. Irving A.S. Batson	Spinning experiments on a single seat fighter with deepened body and raised tailplane. Part I - Model Experiments. R. & M. 1421. December 1931.
	A.V. Stephens	Part II - Nl scale spinning tests. R. & M. 1421. December 1931.
5	H.B. Irving and A.S. Batson	Spinning experiments and calculations on a model of the Fairy IIIF Seaplane with special reference to the effects of floats, tailplane modifications and. floating ailerons ad interceptors. R. & M. 1356. June 1930.
6	Kerr	Full scale spin and recovery characteristics of a conventional straight wing aircraft with five different ratios of the rolling to pitching moments of inertia. (To be publish&)
7	Bamber and Zimmerman	Spinning characteristics of wings. Rectangular blade-Y monoplane wing. NACA Report 519.

FIG. 1.



BODY DAMPING COEFFICIENT $\quad \overline{\ell_{pB}} = \dfrac{\lambda}{S\, b^2} \displaystyle\int_{-\ell_1}^{+\ell_2} \varepsilon\, h\, x^2\, dx$



UNSHIELDED RUDDER VOLUME COEFFICIENT $\quad \overline{\ell\xi} = \dfrac{A_R\, \ell}{S\, b}$

A_R : SHADED AREA

ℓ : DIST. BETWEEN CENTROID OF SHADED AREA AND C.G. OF AIRCRAFT

FIG. 1. BODY DAMPING AND UNSHIELDED RUDDER VOLUME COEFFICIENTS.

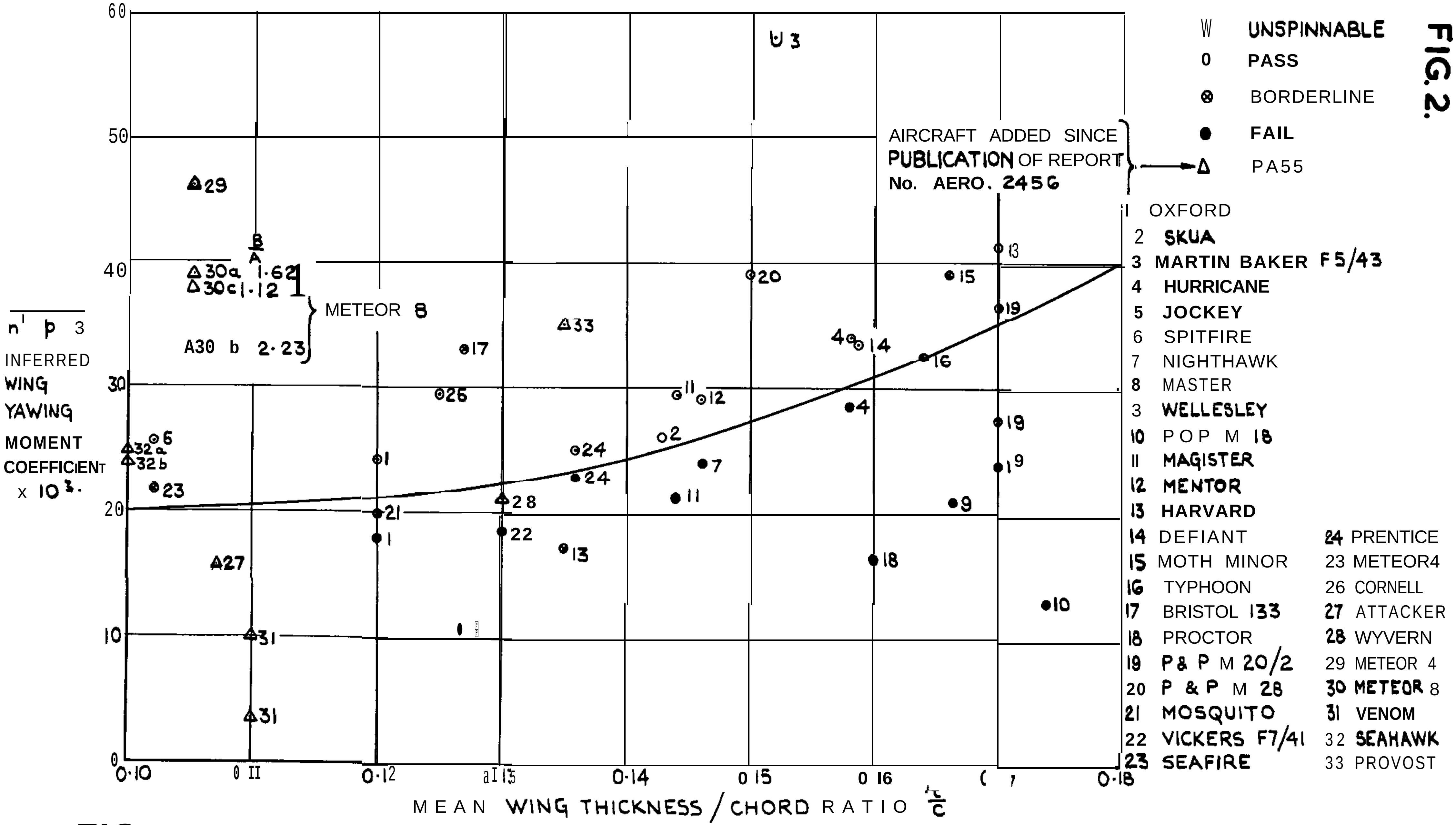


FIG. 2. SUGGESTED CRITERIA FOR RECOVERY BASED ON WING. THICKNESS/ CHORD RATIO.

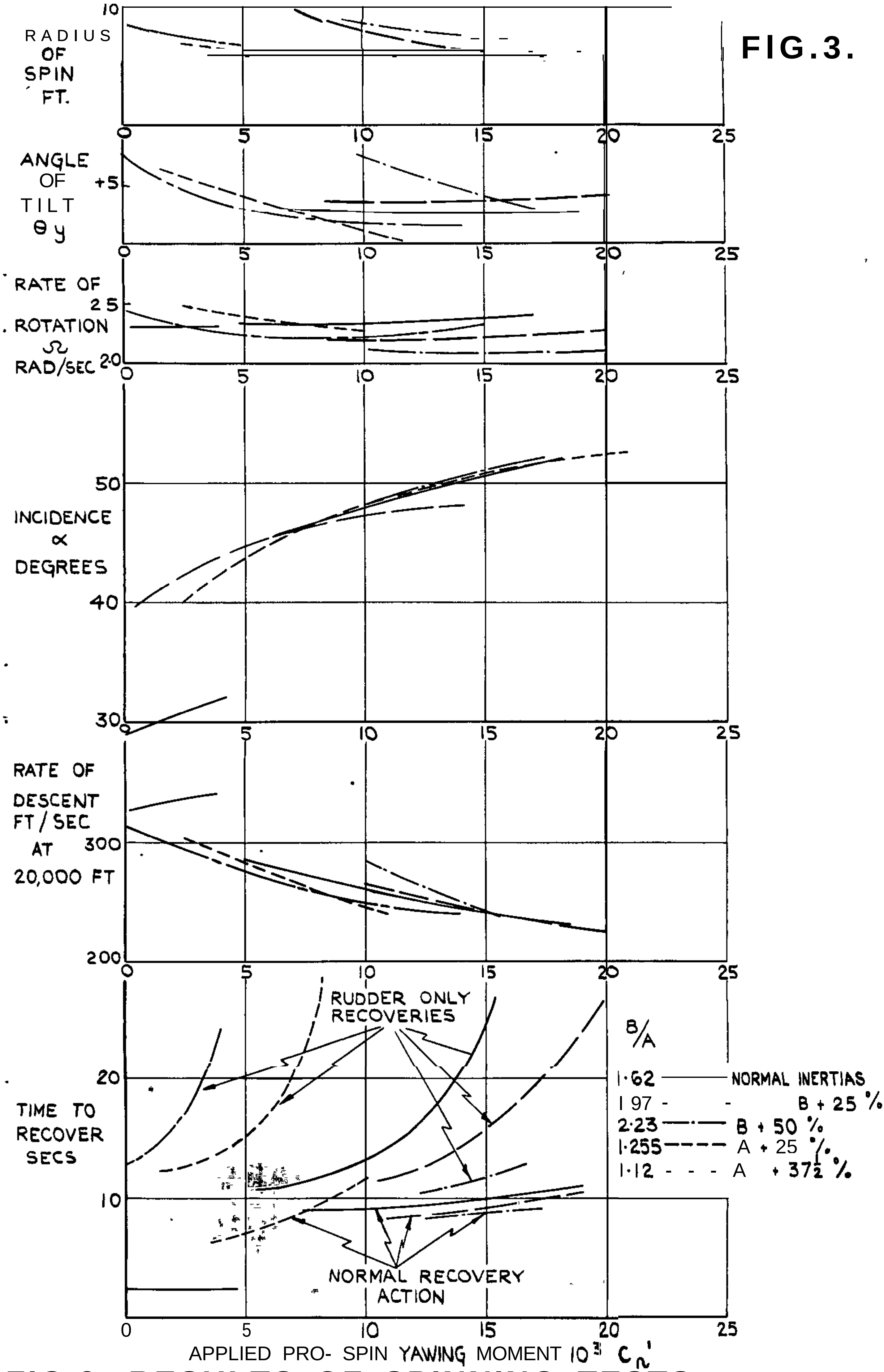


FIG.3. RESULTS OF SPINNING TESTS ON METEOR WH 320.

FIG. 4.

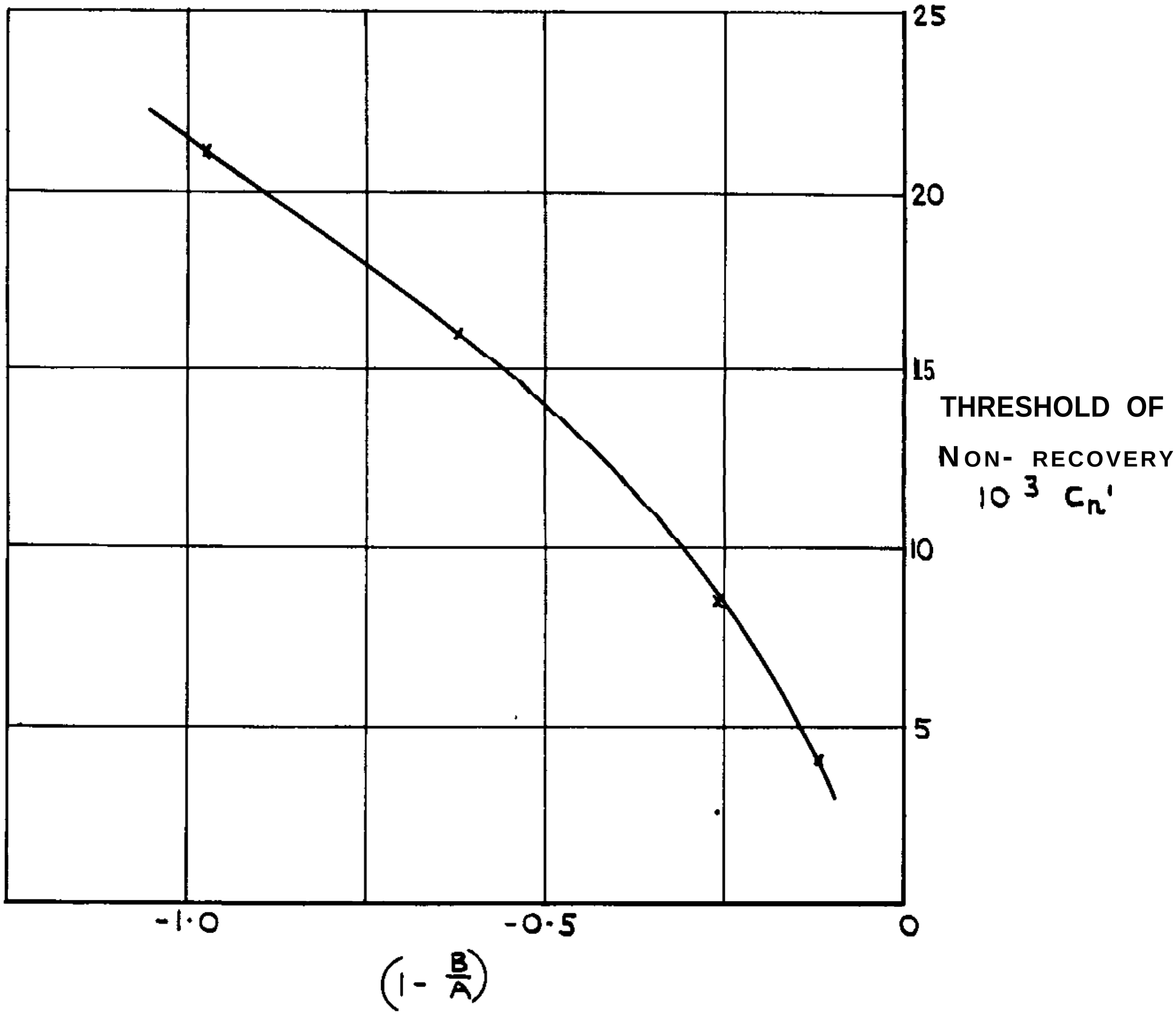


FIG. 4. RECOVERY STANDARD OF METEOR 8 WH 320 FOR RUDDER ONLY R ECOV ERIES.

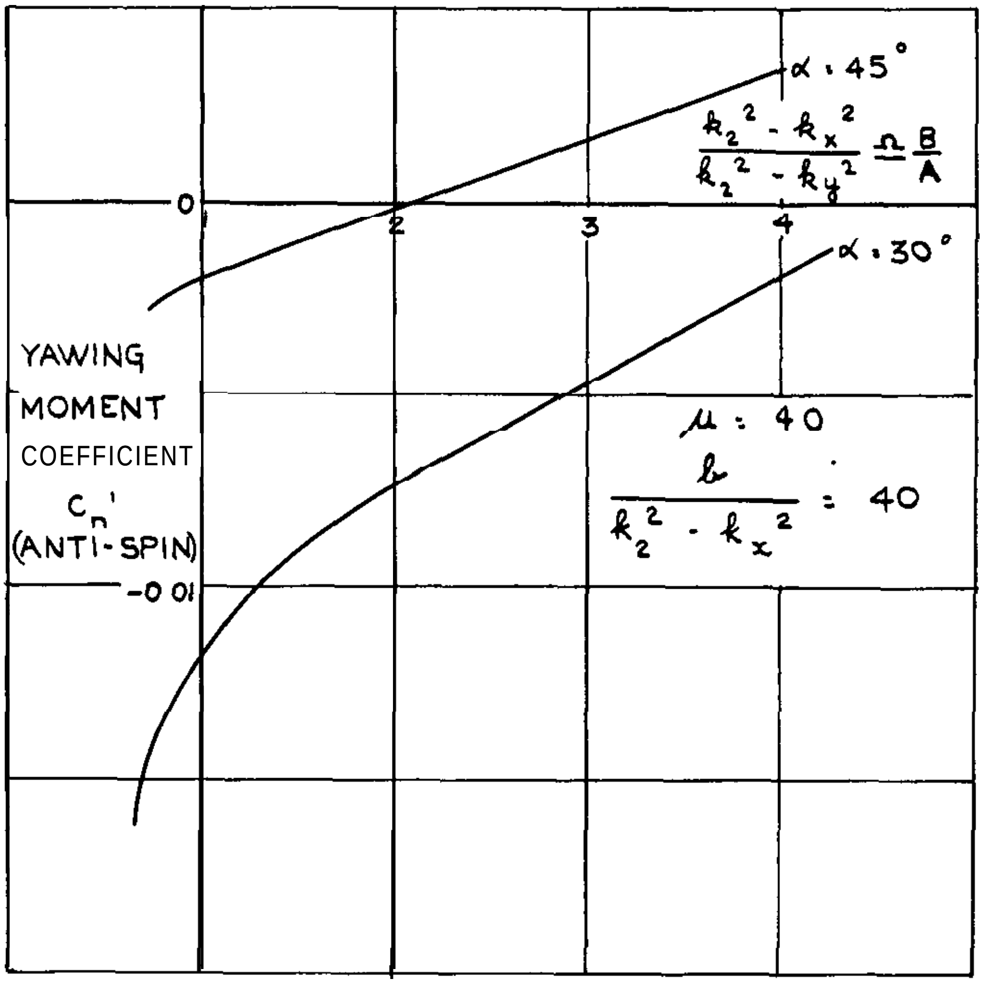


FIG. **5**. EFFECT OF ROLLING **AND** YAWING MOMENT OF INERTIA PARAMETERS UPON THE YAWING MOMENT WHICH **MUST** BE SUPPLIED BY THE AIRCRAFT OTHER THAN THE **WING.** FOR EQUILIBRIUM IN THE SPIN.

FIG, 6.

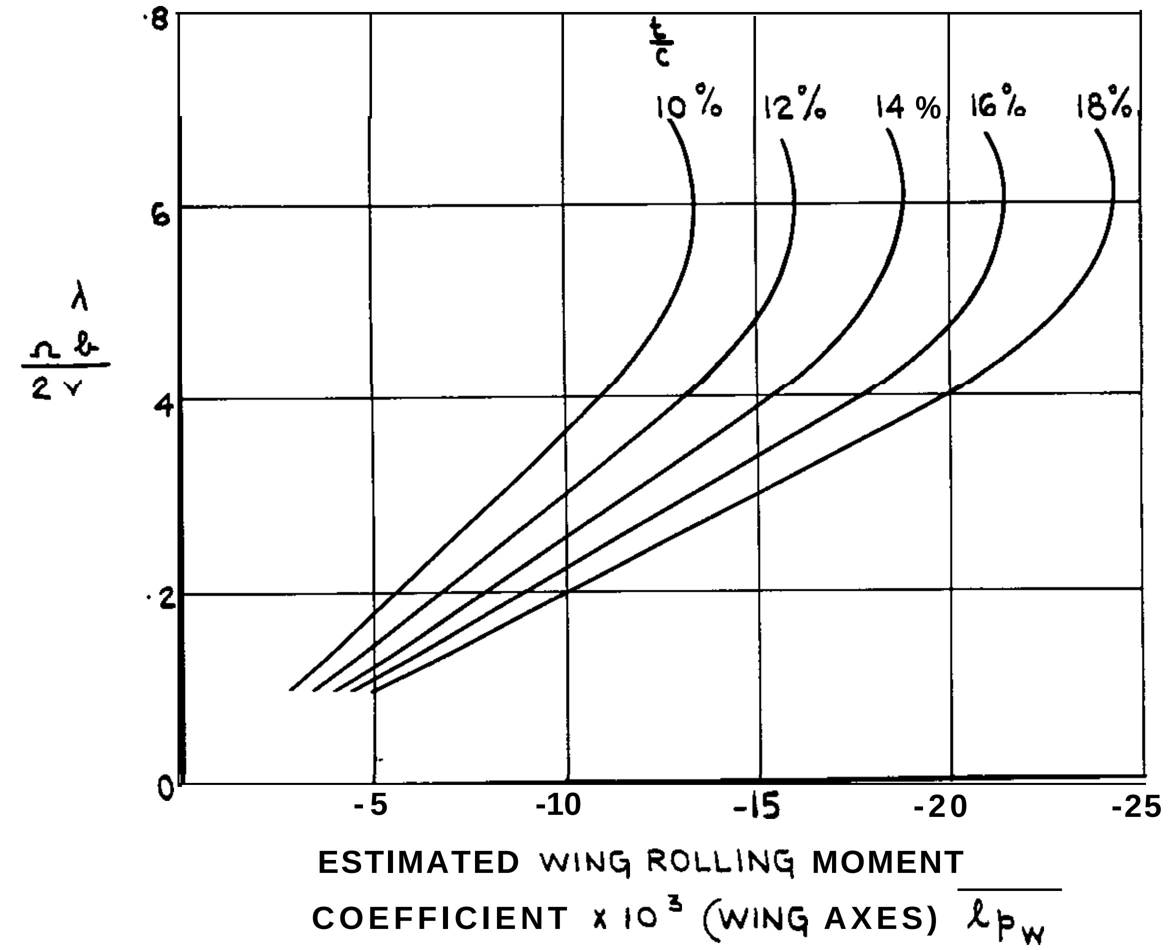


FIG. 6. AN ESTIMATION OF THE WING ROLLING. MOMENT COEFFICIENTS (WIND AXES) IN THE SPIN.

I	OXFORO
2	SKUA
3	MARTIN • BAKER F5/43
4	HURRICANE
5	JOCKEY
6	SPITFIRE
7	NIGHTHAWK
8	MASTER
3	WELLESLEY
10	P & P M 18
11	MAGISTER
12	MENTOR
13	HARVARD
14	DEFIANT
15	MOTH MINOR
16	TYPHOON
17	BRISTOL 133
18	PROCTOR
19	P & P M 20/2
20	P & P M 28
21	MOSQUITO
22	VICKERS F7/41
23	SEAFIRE
24	PRENTICE
2s	METEOR- 4
26	CORNELL
27	ATTACKER
28	WYVERN
25	METEOR 4
30	METEOR 8
31	VENOM
32	SEAHAWK
33	PROVOST
3 4	FIAT G 49

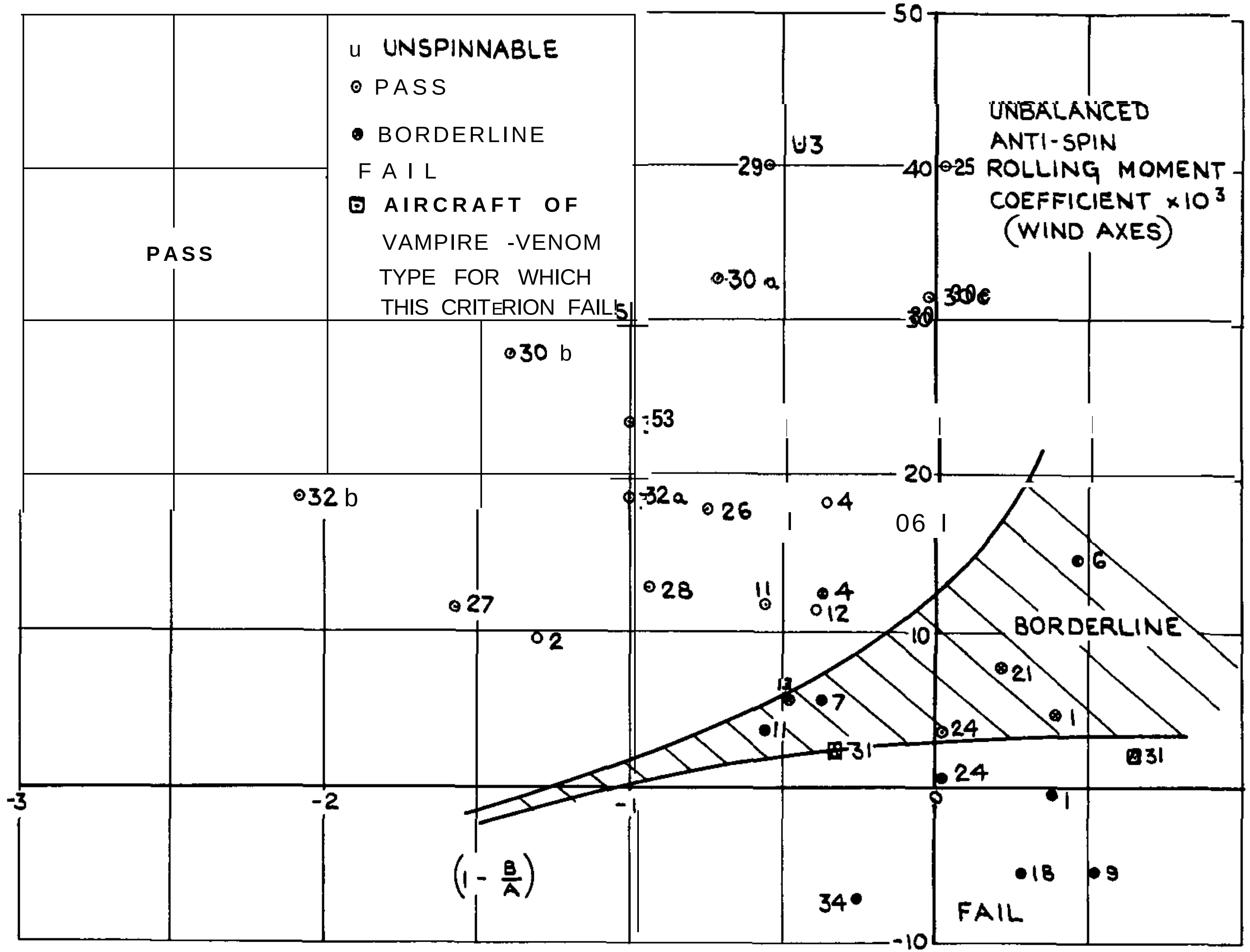


FIG. 7. THE CRITERION FOR THE PREDICTION OF RECOVERY CHARACTERISTICS OF SPINNING AIRCRAFT.

FIG. 7

FIG. 8.

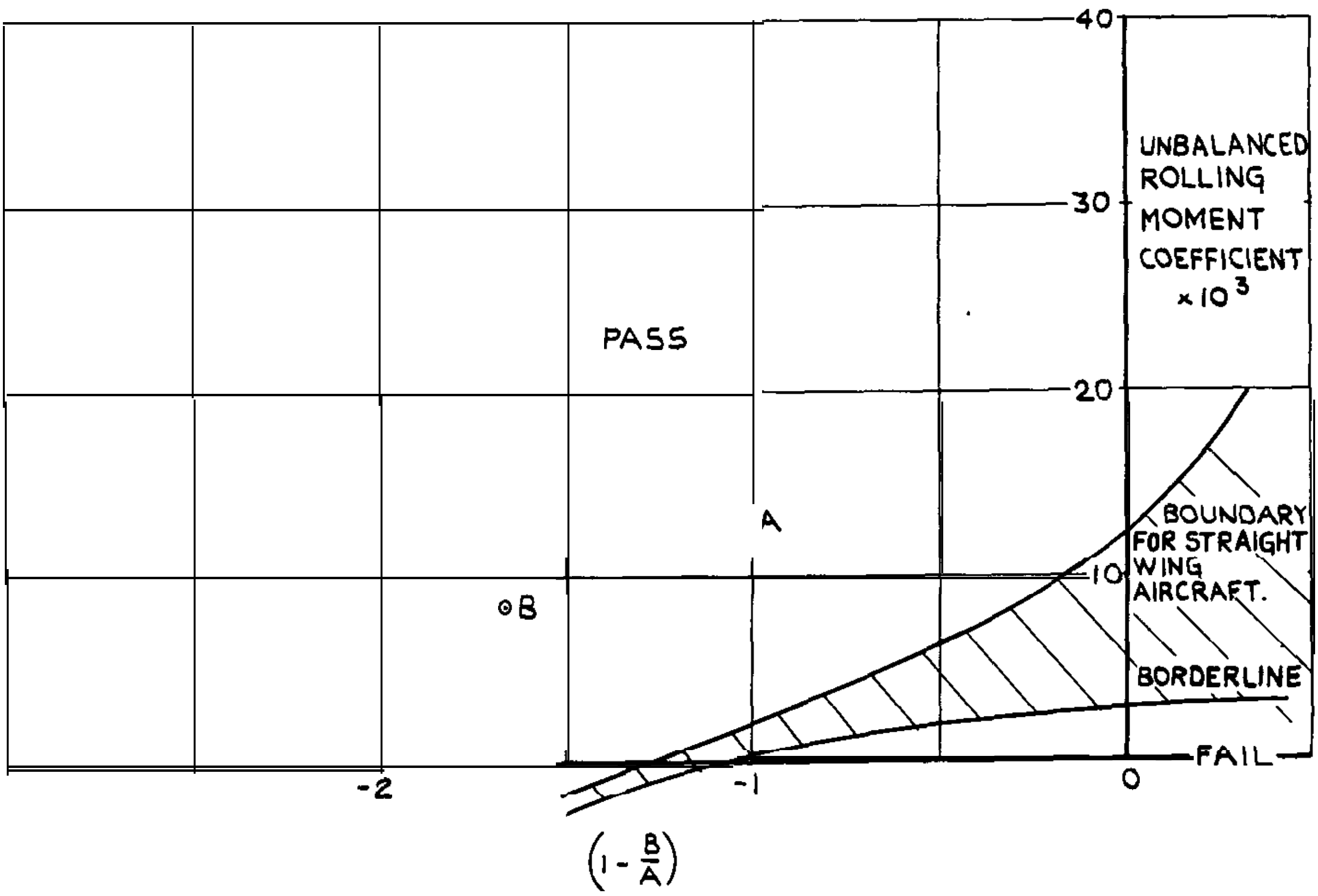


FIG. 8. EXTENSION OF FIG. 6. FOR SWEPT WING AIRCRAFT.

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