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The Relationship between Upward Accelerations and Mean Associated Downward Accelerations Experienced by Aircraft in Manoeuvring Flight

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Summary.

When assessing the fatigue life of an aircraft structure it is necessary to know the frequency of occurrence of upward accelerations and the magnitude of the downward acceleration to be associated with those upward accelerations.

Analysis of V-g records from a variety of types of fighter, training and light-bomber aircraft shows that the mean downward acceleration associated with an upward acceleration can be represented by part of a conic, whose characteristics depend on the type of aircraft, until the upward acceleration exceeds a certain value, when the downward acceleration becomes constant.

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* Replaces R.A.E. Tech. Note No. Structures 297—A.R.C. 23 441.

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1. *Introduction.*

When assessing the fatigue life of an aircraft structure it is necessary to estimate the magnitude of the downward acceleration expected to be reached during initiation of, or recovery from, manoeuvres which produce certain upward accelerations.

Experience of accelerations recorded by counting accelerometers and fatigue-load meters gives the probable frequency of occurrence of upward accelerations. The magnitude of the associated downward accelerations cannot be obtained from these instruments since they record upward and downward accelerations independently. The V-g recorder, however, provides a continuous record of accelerations on a speed base. This paper presents a method of obtaining an approximate answer to the problem.

Fighter aircraft are treated first using V-g records from *Hunter*, *Swift* and *Javelin* aircraft to propound a theory and from *Meteor* 8 and *Meteor* NF11 aircraft to test it. Readings from a step-trace recorder fitted to a *Venom* FB1 aircraft give an independent check. V-g records from *Venom* FB1, *Sea Fury*, *Sea Hawk* and *Wyvern* aircraft are used to illustrate the application of the theory.

Finally analyses of V-g records from *Jet Provost*, *Canberra* and *Gannet* aircraft show that the theory can be applied in a more generalised form to aircraft other than fighters.

2. *Description of Records.*

The type of record obtained from V-g recorders is illustrated in Figs. 1 and 2 which include 16 records from *Meteor* 8 and 8 records from *Meteor* NF11 aircraft. The speed range on the grid is divided into 100 m.p.h. (or 50 m.p.h.) speed bands and the acceleration into $1 \cdot 0g$ or $2 \cdot 0g$ increments.

Extreme upward and downward accelerations are read to the nearest $0 \cdot 1g$ in each 50 m.p.h. band*, starting from 150 or 200 m.p.h. according to the landing speed of the aircraft.

3. *Assumptions.*

Examination of the records shown in Figs. 1 and 2, and numerous other records, shows that upward accelerations are usually applied and/or taken off at fairly constant speed, being followed and/or preceded by an acceleration less than $1 \cdot 0g$. Hence the downward acceleration associated with a particular upward acceleration frequently occurs in the same speed band.

It is assumed (i) in this paper that the extreme upward and downward accelerations in a speed band are associated. This cannot give an under-estimate of the total change of acceleration resulting from a particular manoeuvre except when the associated up and down accelerations actually occur in different speed bands, but over-estimates of the total change can occur whether the truly associated accelerations are in the same speed band or not. Hence, on balance, the assumption made will give an over-estimate of the total change of acceleration more frequently than an under-estimate. The further assumption (ii) that a particular upward acceleration is associated with the mean of the downward accelerations, found by using assumption (i), is therefore likely to over-estimate the change of acceleration. Under-estimates may sometimes occur if the number of times the upward acceleration is reached is very small (say, less than 6).

4. *Quantity of Basic Data.*

The number of records and pairs of readings available from each type of aircraft under consideration is as follows:

Aircraft	Records	Pairs of readings
Hunter Mk. 4	610	3 443
Swift	457	2 758
Javelin Mk. 1	291	1 439
Meteor 8	895	4 634
Meteor NF11	572	2 474
Total	2 825	14 848

* Since 1955, speeds have been calibrated in knots.

The *Hunter* records were originally divided into 6 sets according to duty and altitude, and the *Javelin* records into 4 sets; the results obtained were so similar that they were recombined.

The initial calculations were based on *Hunter*, *Swift* and *Javelin* records; *Meteor* 8 (in 3 sets, one from each of 3 separate V-g recorder trials) and *Meteor* NF11 records were used to test and consolidate the theory evolved.

The correlation diagrams of upward acceleration against downward acceleration are given in Tables 1 to 5 for individual aircraft types and in Table 6 for all aircraft. For the sake of brevity correlation diagrams for the smaller sets of results are omitted.*

5. *Correlation Coefficients.*

The correlation coefficient (r) between the upward and downward accelerations is as follows for three of the aircraft types, φ representing the number of degrees of freedom associated with each value of r:

Aircraft type	All readings		Max. and min. values of r			
	r	φ	r	φ	r	φ
Hunter	0·47	3 441	0·55	460	0·36	561
Swift	0·42	2 756	—	—	—	—
Javelin	0·48	1 437	0·51	653	0·36	154†

† 154 is also the smallest value of φ.

A correlation coefficient greater than 0·321 is significant at the 0·1% level with more than 102 pairs of readings ($\varphi > 100$). Hence, the chance that the correlation between upward and downward accelerations is accidental, is less than 1 in 1000 for every set of readings considered.

6. *Regression Lines.*

Having determined that there is a close relationship between the magnitudes of upward and downward accelerations, the regression line of downward upon upward accelerations was calculated for the *Hunter*, *Swift* and *Javelin*. These are presented in Figs. 3 to 5, and points representing the mean downward acceleration associated with each upward acceleration in 0·1g steps are plotted on the same diagrams. Means representing less than six pairs of readings are ringed. It can be seen that, although the regression lines fit the majority of the points reasonably well, the fit is not good near 1·0g and when y is large. In each case the means appear to follow a curved line rather than the straight regression line.

7. *Representative Curves.*

It is observed from plots of mean downward acceleration against upward acceleration that when y is large the points approach tangentially or are grouped about the line $x = 0$. The least value

* The original readings are in 0·1g steps, which are used in the calculations; the tables are presented with readings collected in 0·3g steps to reduce their size.

(m) of y associated with $x = 0$ varies with type of aircraft and type of flying. Figs. 1 and 2 show that the number of negative accelerations is few compared with the number of accelerations of $0 \cdot 0g$; records c, f, j, l, m, n, o and p of Fig. 1, are of particular interest in this respect.

In the area bounded by $x = 1$, $x = 0$, $y = 1$, $y = m$ the points follow approximately a smooth curve which touches $x = 0$ at $(0, m)$ and $x = y$ at $(1, 1)$. The best fit is part of the conic

$$(y-m)^2 = (m-1)\,x\,[2(m-2) - x(m-3)],$$

where m may be determined by substituting $x = 1 \cdot 05\bar{x} - 0 \cdot 05$ and $y = 0 \cdot 95\bar{y} + 0 \cdot 05$ in the equation; $\bar{x}$ and $\bar{y}$ are the overall mean downward and upward accelerations respectively. (This method of finding m was reached by trial and error.)

Values of m derived from the results from each type of aircraft, and all the results together, are given below; the maximum and minimum values for the smaller sets of results from *Hunter* and *Javelin* aircraft by type of flying are also given.

Aircraft type	m	Max. m	Min. m
Hunter	12	14	8
Swift	7	—	—
Javelin	3·5	4	2·5
All aircraft	7·5	—	—

The representative curves for the *Hunter*, *Swift* and *Javelin* are shown in Figs. 3, 4 and 5 respectively.

8. *Test of Validity of Derived Theory.*

Readings from *Meteor* 8 and *Meteor* NF11 aircraft are used to test the theory that: (i) for fighter aircraft the downward acceleration associated with upward accelerations greater than mg is expected to be $0g$; (ii) the downward acceleration plotted against upward acceleration is expected to follow the curve

$$(y-m)^2 = (m-1)x\,[2(m-2) - x(m-3)]$$

in the area bounded by $x = 1$, $x = 0$, $y = 1$, $y = m$; (iii) m may be determined by substituting $x = 1 \cdot 05\,\bar{x} - 0 \cdot 05$ and $y = 0 \cdot 95\bar{y} + 0 \cdot 05$ in the equation.

The values of m calculated for the *Meteor* 8 and *Meteor* NF11 are 5 and 10 respectively, the joint value of m being 6·5; for the three separate *Meteor* 8 trials (cf. Section 4) m varies from 4·5 to 8. In each case the calculated curve fits the plot of mean downward acceleration against upward acceleration. This is illustrated in Figs. 6 and 7 which give the curves and plotted points for the *Meteor* 8 and *Meteor* NF11 respectively.

When the *Hunter*, *Swift*, *Javelin*, *Meteor* 8 and *Meteor* NF11 readings are taken together the calculated value of m is 7; the curve and plotted points are shown in Fig. 8.

9. *Independent Check on Results.*

Readings from a step-trace recorder, calibrated in $1 \cdot 0g$ steps, fitted to a *Venom* FB1 aircraft show that 93·4% of the 2 010 peak accelerations recorded were associated with downward accelerations between $0 \cdot 0g$ and $1 \cdot 0g$. Of the remainder, $0 \cdot 6\%$ fell below $0 \cdot 0g$ and $6 \cdot 0\%$ failed to drop below $1 \cdot 0g$ on the recovery. These results are not incompatible with the findings based on V-g records; they indicate that the adoption of the formula given in Section 7 when preparing load spectra for fatigue investigations should give reasonable and slightly conservative results.

10. *Application to Other Fighter Aircraft.*

V-g records are not available for all types of fighter aircraft; even when available the labour involved in calculating m is considerable, particularly when it is desired to check the result by preparing plots of mean downward acceleration against upward acceleration.

m has, however, been calculated, without using the check, for the *Venom* FB1 (6 sets of records), *Sea Hawk* (2 sets), *Sea Fury* (4 sets) and *Wyvern* (5 sets). The results are as follows:

Aircraft type	Records	Readings	m	Max. m	Min. m
Venom	1 287	5 764	8	10	4
Sea Fury	554	2 163	7	8	7
Sea Hawk	308	1 710	7	7	7
Wyvern	584	2 310	9	12	6
Naval Aircraft	1 446	6 183	8	—	—

These results are fairly centrally placed between the limits obtained in the first calculations ($2\frac{1}{2}$ to 14). The difference between the values of m for all R.A.F. aircraft (7) and all Naval aircraft (8) is not significant; in both instances the value before correcting to the nearest whole number lay between 7 and 8.

Fig. 9 may be used to obtain the downward acceleration (x) (to the nearest $0 \cdot 1g$) which is associated with any value of the upward acceleration (y), for all values of m from $2\frac{1}{2}$ to 14, where $(y-m)^2 = (m-1)\,x\,[2(m-2) - x(m-3)]$.

It is suggested that when V-g records are not available, and hence m is unknown, the chosen value of m for a fighter should be less than $7\frac{1}{2}$. Usually a value of 5 should be sufficiently stringent although it should be noted that a value of $2\frac{1}{2}$ can be obtained.

11. *Consideration of Other Aircraft Types.*

11.1. *Data Used.*

Full analyses, similar to those on the *Hunter, Swift* and *Javelin*, have been made of the results from the *Jet Provost* Trainer, *Canberra* B8 and *Gannet. Jet Provost* readings were originally divided into 'aerobatics', 'circuits and landings' and 'miscellaneous'; results obtained from the last two sets are so alike that they are combined herein to form a single set 'other duties', while 'aerobatics' remains separate. Records from *Canberra* B2 Operational, *Canberra* B2 Training, *Canberra* B6 excluding Ground Attack and *Canberra* B6 Ground Attack were analysed in the same manner as *Meteor* 8 and *Meteor* NF11 records.

The following table gives the numbers of records and pairs of readings for each set of records and the correlation coefficient (r) and number of degrees of freedom (φ) for the *Jet Provost, Canberra* B8 and *Gannet*.

Aircraft type	Records	Readings	r	φ
Jet Provost (A.)	270	876	0·36	874
Jet Provost (O.D.)	334	887	0·40	885
Canberra B8	486	2 044	0·51	2 042
Gannet	221	809	0·51	807
Canberra B2 (Ops.)	588	3 239	—	—
Canberra B2 (Tr.)	629	3 760	—	—
Canberra B6 (ex. G.A.)	479	1 566	—	—
Canberra B6 (G.A.)	92	373	—	—

As in Section 5, the chance that the correlation between upward and downward accelerations is accidental is less than 1 in 1000 for the four sets of readings considered.

The correlation diagrams are given in Tables 7 to 14.

11.2. *Regression Lines.*

The regression lines are shown in Figs. 10 to 13. As before, the fit is not good near $1\cdot0g$ or when y is large.

11.3. *Representative Curves.*

The plots of mean downward against upward acceleration follow a curved line in the region $x = 1$ to $x = p$, $y = 1$ to $y = m$ and are then grouped about $x = p$. For fighter aircraft $p = 0$ and m varies with the aircraft type (cf. Section 7). For other aircraft the values of p and m and the derived equation are as follows:

Aircraft type	p	m	Equation
General	p	m	$(y-m)^2 = \dfrac{(m-1)}{(1-p)^2}(x-p)\,[2(1-p)(m+p-2) - (x-p)(m+2p-3)]$
Jet Provost (A.)	$-0\cdot5$	8	$9(y-8)^2 = 7(2x+1)(29-8x)$
Jet Provost (O.D.)	0	$4\frac{1}{2}$	$(2y-9)^2 = 7x(10-3x)$
Canberra B8	0·25	3	$9(y-3)^2 = 4(4x-1)(4-x)$
Gannet	0·25	3	$9(y-3)^2 = 4(4x-1)(4-x)$
Canberra B2 (Ops.)	0·25	$2\frac{1}{2}$	$(2y-5)^2 = 3(4x-1)$
Canberra B2 (Tr.)	0·25	2	$9(y-2)^2 = (4x-1)(2x+1)$
Canberra B6 (ex. G.A.)	0·25	$3\frac{1}{2}$	$9(2y-7)^2 = 5(4x-1)(23-8x)$
Canberra B6 (G.A.)	0	6	$(y-6)^2 = 5x(8-3x)$

Each of these equations is a conic touching $x = p$ at (p, m) and $x = y$ at $(1, 1)$. The curves are shown in Figs. 10 to 17.

12. *Conclusions.*

(i) The downward acceleration (x) associated with any upward acceleration (y) is given by the equation

$$(y-m)^2 = \frac{(m-1)}{(1-p)^2}(x-p)\,[2(1-p)\,(m+p-2) - (x-p)\,(m+2p-3)]$$

in the region bounded by $x = 1$, $x = p$, $y = 1$, $y = m$ and remains constant at $x = p$ when $y \geqslant m$; p and m depend on the aircraft type.

(ii) For fighter aircraft $p = 0$ and the equation becomes

$$(y-m)^2 = (m-1)\,x\,[2(m-2) - x(m-3)]\,;$$

m may have any value from $2\frac{1}{2}$ to 14, with a most likely value of $7\frac{1}{2}$, and a suggested value for 'unknown' aircraft of 5.

(iii) For training aircraft engaged on aerobatics $p = -0{\cdot}5$ and $m = 8$; when engaged on other duties $p = 0$, $m = 4\frac{1}{2}$.

(iv) For light-bomber aircraft except on ground attack $p = 0{\cdot}25$ and m may have any value from 2 to $3\frac{1}{2}$, the most likely value being 3.

For light bombers on ground attack, $p = 0$ and $m = 6$.

TABLE 1

Correlation Diagram of Upward vs. Downward Acceleration
Hunter Mk. 4

Upward acceleration (g)	Associated downward accelerations (g)										
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5	−1·8	−2·1
1·1	317	29	6								
1·4	261	129	25	4	1						
1·7	253	148	53	6		2					
2·0	189	168	81	27	1						
2·3	115	125	62	30	3						
2·6	83	110	50	18	2	1	1				
2·9	93	129	92	28	4	1	2				
3·2	40	52	38	26	5	1	2				
3·5	29	54	41	18	4	3	3				
3·8	30	52	34	19	4	4	1	1			
4·1	21	36	22	27	1	1	1			1	1
4·4	12	26	18	14	2	2	3	2			
4·7	9	17	23	12	2	1	3	1			
5·0	4	14	9	4	2	1	4	2	3		
5·3	3	1	5	1	2	1	1				
5·6	2		1			1	1				
5·9	1		4	2			1		1		
6·2			1								
6·5		3									

TABLE 2

Correlation Diagram of Upward vs. Downward Acceleration
Swift Mk. 1

Upward acceleration (g)	Associated downward accelerations (g)											
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5	−1·8	−2·1	−3·0
1·1	11	4										
1·4	46	52	9	2	1							
1·7	61	126	45	6		1						
2·0	53	138	81	23	3	1	1					
2·3	24	70	62	22	2							
2·6	19	53	73	34	3	1	1	1				
2·9	28	68	103	62	10	4	3	2				
3·2	5	41	69	47	6	7	1					
3·5	10	39	65	56	11	7	4	2				
3·8	9	39	63	76	14	8	6					
4·1	5	31	54	76	18	8	7		2	1	1	
4·4	10	22	44	69	16	5	6	2	1	2		
4·7	6	21	37	42	9	5	4	1				1
5·0	9	16	43	38	14	8	4	2	2	1		
5·3	5	13	25	17	5	2	3	3				
5·6	3	10	17	17	6	3	1			1		
5·9	3	7	12	12	3	3	4	1	1			
6·2	4	1	2	4	3							
6·5		2	1	4	1							
6·8	1	1	3	2		1	1					
7·1	2			2	1		1					
7·4			2	1								
7·7		2	1									
8·0				1								

TABLE 3

Correlation Diagram of Upward vs. Downward Acceleration
Javelin Mk. 1

Upward acceleration (*g*)	Associated downward accelerations (*g*)													
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5	−1·8	−2·1	−2·4	−2·7	−3·0
1·1	15	5	3											
1·4	38	85	23	4	1	1								
1·7	42	125	93	21	1				1					
2·0	16	79	115	79	5	6	5		2					
2·3	8	23	57	40	11	2	3	1						1
2·6	3	16	34	31	10	4	3	1	2					
2·9	3	12	41	48	14	16	15	2	1					
3·2	3	7	15	22	8	7	2	1	3		1			
3·5		5	14	13	4	7	7	1		1				
3·8	3	7	12	11	6	1	7	1	1					
4·1	2	6	10	11	6	4	3			1				
4·4	2	2	4	4	3	4	3			1				
4·7	1	3	3	1		2	1			3	2			
5·0			1	2	1	1		1		2				
5·3	1		2	2		1								
5·6			1	1										
5·9														
6·2				1		1								
6·5					1									
6·8														
7·1														
7·4		1												

TABLE 4

Correlation Diagram of Upward vs. Downward Acceleration
Meteor Mk. 8

Upward acceleration (*g*)	Associated downward accelerations (*g*)												
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5	−1·8	−2·1	−2·4	−2·7
1·1	67	43	15	7			1		1				
1·4	110	221	54	26	6	4		2					
1·7	88	154	74	33	10	2	3						1
2·0	83	171	110	75	19	4	6	1					
2·3	48	127	80	59	20	9	4						
2·6	40	131	73	59	15	14	1	1	3				
2·9	50	142	114	100	36	14	11	1	2				
3·2	25	103	80	82	38	14	12	6	1				
3·5	12	84	50	77	31	24	15	5	1			1	
3·8	14	63	90	83	42	18	20	3	2	4			
4·1	10	59	68	68	29	21	11	9	3	3			
4·4	3	32	43	68	25	17	13	5	4	4	2		
4·7	4	20	30	37	27	13	12	4		1			
5·0	7	21	42	37	24	13	11	4	3				
5·3	1	6	12	29	10	13	4	6	1	2			
5·6	4	4	4	13	11	7	5	3	2				
5·9	4	5	14	15	10	3	5	4			1		
6·2		4	6	6	5	2	1						
6·5		2	1	5	3	1	1	1			1		
6·8	1		2	9	4		2	2					
7·1		2		3	2	1	1						
7·4			1	1	1				1	1			
7·7													
8·0		1	1	5			1						
8·3				3	1								
8·6													
8·9							1						

TABLE 5

Correlation Diagram of Upward vs. Downward Acceleration
Meteor NF11

Upward acceleration (g)	Associated downward accelerations (g)												
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5	−1·8	−2·1	−2·4	−2·7
1·1	156	29	5										
1·4	184	170	30	6	1	1							
1·7	180	148	57	4	4								
2·0	112	148	56	13	6	1	2						
2·3	88	86	48	13	2	3	1			1			
2·6	55	83	45	10	2	1						1	
2·9	56	108	52	22	9	4	2		2				
3·2	34	60	30	12	4	7	1		2				
3·5	25	41	23	14	2	3	2			1			
3·8	17	27	21	11	3	4	5	1					
4·1	13	33	16	10	5	4							1
4·4	7	19	13	9	3	1	1		1				
4·7	5	9	6	7	2								
5·0	1	10	7	4									
5·3	3	4	7	2			1						
5·6	1		1	2	1								
5·9	1	2			1		1						
6·2			1	1									
6·5					1								

TABLE 6

Correlation Diagram of Upward vs. Downward Acceleration
Total R.A.F. Fighters

Upward acceleration (g)	Associated downward accelerations (g)													
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5	−1·8	−2·1	−2·4	−2·7	−3·0
1·1	566	110	29	7			1		1					
1·4	639	657	141	42	10	6		2						
1·7	624	701	322	70	15	5	3		1				1	
2·0	453	704	443	217	34	12	14	1	2					
2·3	283	431	309	164	38	14	8	1		1				1
2·6	200	393	275	152	32	15	6	3	5			1		
2·9	230	459	402	250	73	39	33	5	5					
3·2	107	263	232	189	61	36	18	7	6		1			
3·5	76	223	193	178	52	44	31	8	1	2		1		
3·8	73	188	220	200	69	35	39	6	3	4				
4·1	51	165	170	192	59	38	22	9	5	6	2		1	
4·4	34	99	122	164	49	29	26	9	6	7	2			
4·7	25	70	99	99	40	21	20	6		4	2			1
5·0	21	61	101	84	41	23	19	9	8	3				
5·3	14	24	51	51	17	17	9	9	1	2				
5·6	10	14	24	33	18	11	7	3	2	1				
5·9	9	14	30	29	14	6	11	5	2		1			
6·2	4	5	10	12	8	3	1							
6·5		7	2	9	6	1	1	1			1			
6·8	2	1	5	11	4	1	3	2						
7·1	2	2	2	3	3	1	2							
7·4		1	3	2	1				1	1				
7·7		2	1											
8·0		1	2	5			1							
8·3				3	1									
8·6														
8·9							1							

TABLE 7

Correlation Diagram of Upward vs. Downward Acceleration
Jet Provost Mk. 1—Aerobatics

Upward acceleration (g)	Associated downward accelerations (g)												
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5	−1·8	−2·1	−2·4	−3·6
1·1	17	4	1										
1·4	12	25	4										
1·7	10	28	17	4	1		1						
2·0	10	18	19	15	1	1	1	1		1			
2·3	9	11	10	13	2	2	1			1			
2·6	9	15	16	17	3	5	2	1					
2·9	18	29	21	38	4	12	15	3	1	1			
3·2	14	21	12	17	3	5	11	2		1	1		
3·5	12	11	15	11	7	4	11	6	8	2			
3·8	17	12	21	15	3	7	11	3	1	2			
4·1	5	16	13	13	3	2	6	4	4	1			
4·4		1	5	6	5	1	4	5		1			
4·7	5	5	1	4	3			1	1		3		
5·0	3	7	4	5	2		2				1		
5·3			2	1					1	2		1	
5·6	1		1			2					1	1	
5·9	1						1						1
6·2				1									
6·5													
6·8										1			

TABLE 8

Correlation Diagram of Upward vs. Downward Acceleration
Jet Provost Mk. 1—Other Duties

Upward acceleration (*g*)	Associated downward accelerations (*g*)								
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2	−1·5
1·1	49	10	2						
1·4	53	52	32	3					
1·7	27	79	58	17					
2·0	26	60	67	45	2	2	1		
2·3	4	16	24	10	1	1			
2·6	6	16	17	13	3	1	1	1	
2·9	10	19	21	21	4		3	2	1
3·2	4	4	14	7	1		1		
3·5	2	4	7	4	1		2	3	1
3·8	3	5	5	6	1	1			
4·1	5	5	4	4	1		3	1	
4·4			1			1			
4·7	1	2	1				1		
5·6				1					

TABLE 9

Correlation Diagram of Upward vs. Downward Acceleration
Canberra B8

Upward acceleration (*g*)	Associated downward accelerations (*g*)							
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9	−1·2
1·1	49	26	3					
1·4	77	307	62	7				
1·7	44	262	164	19	3			
2·0	29	179	179	59	1		1	
2·3	10	49	82	39	4	3	1	
2·6	7	41	59	28	6		1	
2·9	6	26	62	26	9	3		2
3·2	1	11	18	10	1	1		
3·5	1	6	12	11	4	1		
3·8		3	5	10				1
4·1	1		2	3		2		
4·4		2		1				
4·7							1	
5·0								
5·3		1						

TABLE 10

Correlation Diagram of Upward vs. Downward Acceleration
Gannet A/S Mk. 1

Upward acceleration (*g*)	Associated downward accelerations (*g*)						
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9
1·1	43	10	1				
1·4	55	108	12	3			
1·7	34	113	64	4	1		
2·0	14	46	56	34	3		
2·3	4	15	18	24	4		
2·6	9	18	16	11	6	2	
2·9	4	10	8	17	4	1	
3·2	1	3	4	7		1	1
3·5		3	3	4	2		
3·8		1		1			
4·1			1				
4·4				1			
4·7		2	1				
5·0			1				

TABLE 11

Correlation Diagram of Upward vs. Downward Acceleration
Canberra B2—Operational

Upward acceleration (*g*)	Associated downward accelerations (*g*)						
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9
1·1	284	125	5	2			
1·4	260	872	207	65	9		
1·7	90	401	248	113	16	2	
2·0	20	125	110	58	16	3	
2·3	8	25	29	19	11	3	
2·6	3	11	15	2	4	1	1
2·9	5	13	9	4			
3·2	2	8	6	2	1		1
3·5	2	5	2				
3·8	2	2	3	2		1	
4·1	1	2	1				
4·4							
4·7		1					
5·0		1					

TABLE 12

Correlation Diagram of Upward vs. Downward Acceleration
Canberra B2—Training

Upward acceleration (g)	Associated downward accelerations (g)						
	0·9	0·6	0·3	0	−0·3	−0·6	−0·9
1·1	139	62	25	9	1		
1·4	109	616	269	98	22	5	2
1·7	68	456	541	226	29	13	4
2·0	21	198	258	177	22	4	2
2·3	5	50	68	37	7	6	1
2·6	4	21	44	19	4		1
2·9		10	17	12	2		1
3·2	1	6	13	6	1		
3·5	1	4	2	6	2		
3·8		2	2	2			
4·1		2	7	2			
4·4		2	1	1			
4·7		2		1			
5·0			2				
5·3				2			
5·6			1				
5·9		1	1				
6·2							
6·5		1	1				

TABLE 13

Correlation Diagram of Upward vs. Downward Acceleration
Canberra B6 (Excluding Ground Attack)

Upward acceleration (*g*)	Associated downward accelerations (*g*)				
	0·9	0·6	0·3	0	−0·3
1·1	155	14	1		
1·4	122	216	43	2	
1·7	95	167	100	16	2
2·0	72	132	104	32	1
2·3	16	44	45	17	1
2·6	11	25	22	10	1
2·9	7	21	19	11	1
3·2	2	6	6	4	2
3·5	2	1		2	
3·8		3	4	3	
4·1	1	1	1	1	
4·4			2		

TABLE 14

Correlation Diagram of Upward vs. Downward Acceleration
Canberra B6—Ground Attack

Upward acceleration (*g*)	Associated downward accelerations (*g*)					
	0·9	0·6	0·3	0	−0·3	−0·6
1·1	11	2	1			
1·4	7	19	5	1		
1·7	13	31	8	2		
2·0	21	23	22	10		1
2·3	12	7	11	6	1	
2·6	4	6	9	10		
2·9	6	12	12	23	1	
3·2		3	9	13		1
3·5	2	2	6	7	1	
3·8	1	1	6	5		
4·1			3	6		
4·4	1	1		5		
4·7				2		
5·0			1			

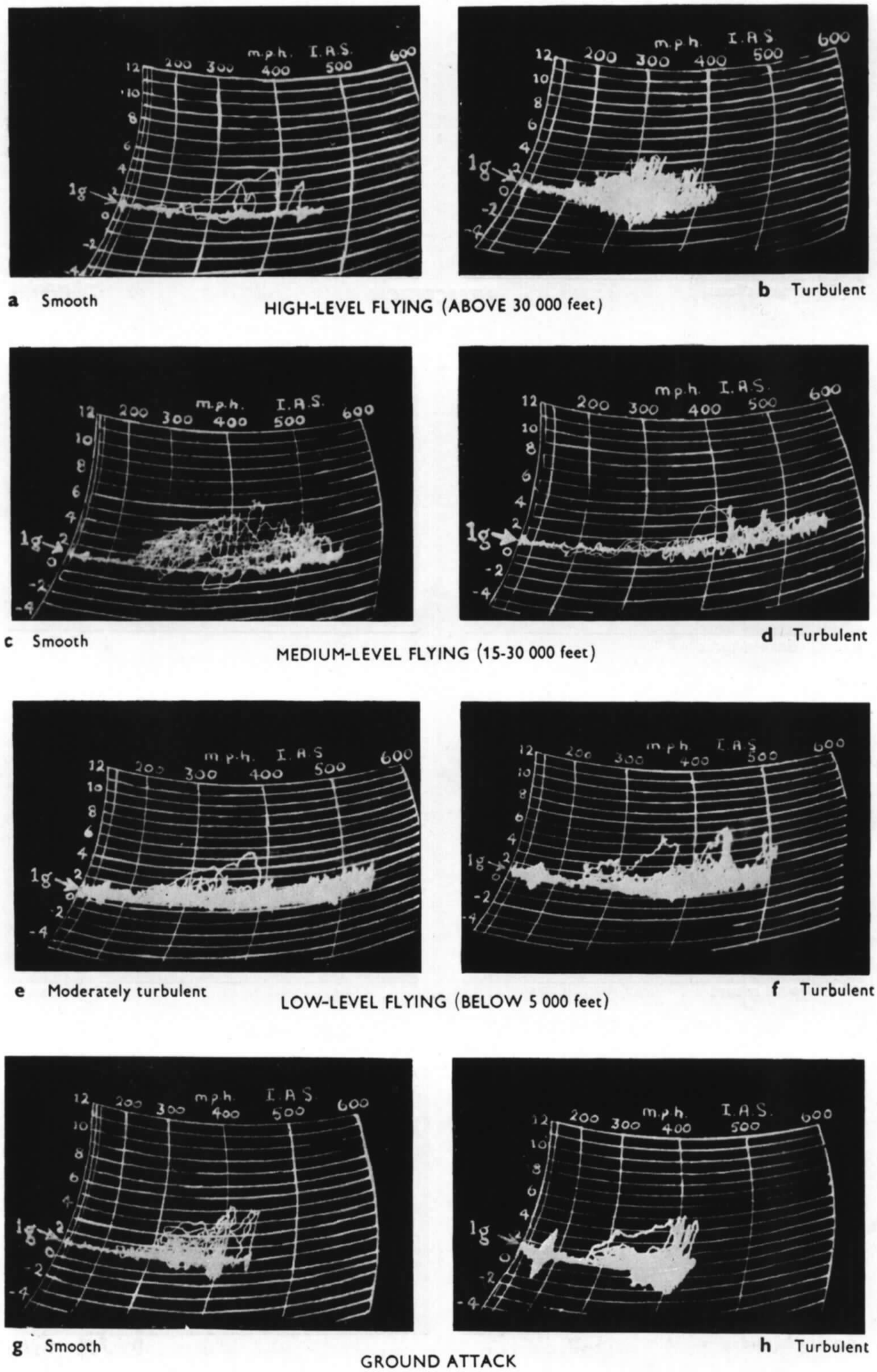
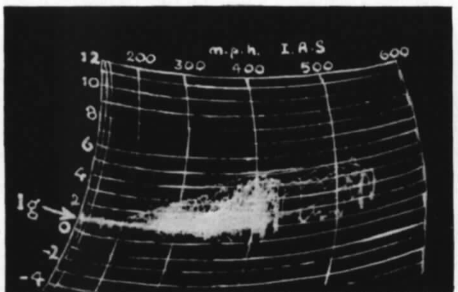
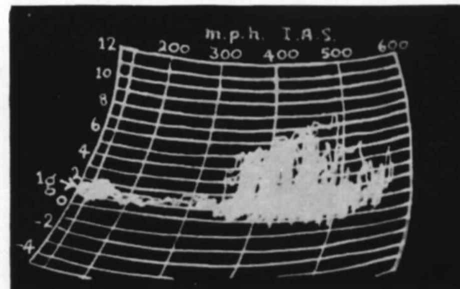


FIG. 1a to h. Examples of V-g records from *Meteor* 8 aircraft.

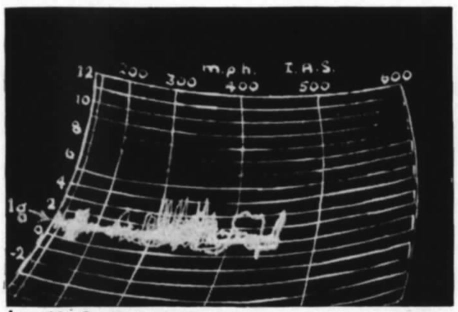


i Slipstream effects

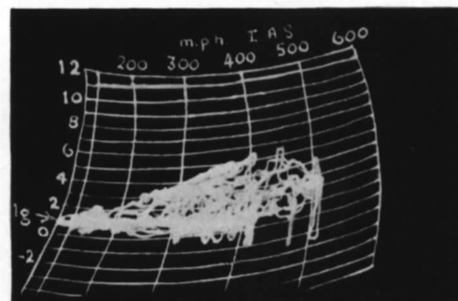


j 8g Recorded

INTERCEPTION

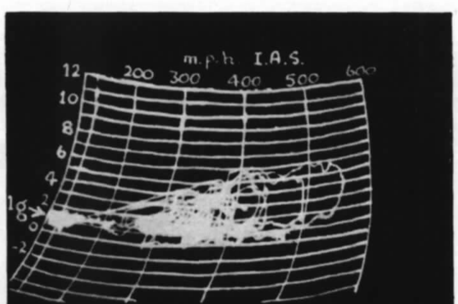


k 90° Banked turns

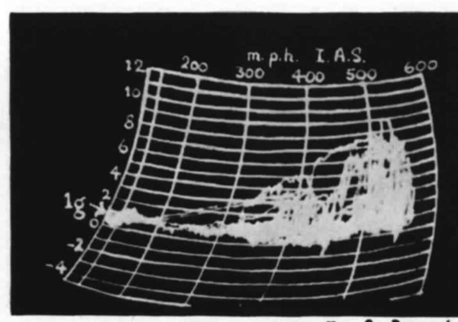


l Buffetting

INTERCEPTION

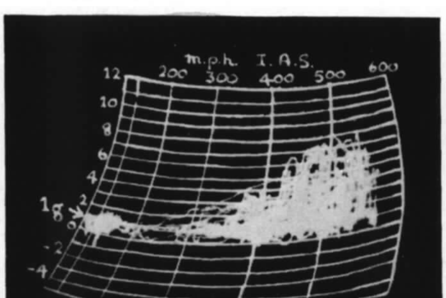


m Typical record

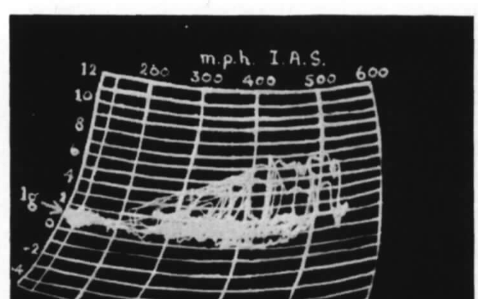


n 9g Recorded

AEROBATICS



o 8g Recorded



p 7g Recorded

ANTI-g SUIT TRIALS

FIG. 1i to p. Examples of V-g records from *Meteor* 8 aircraft.

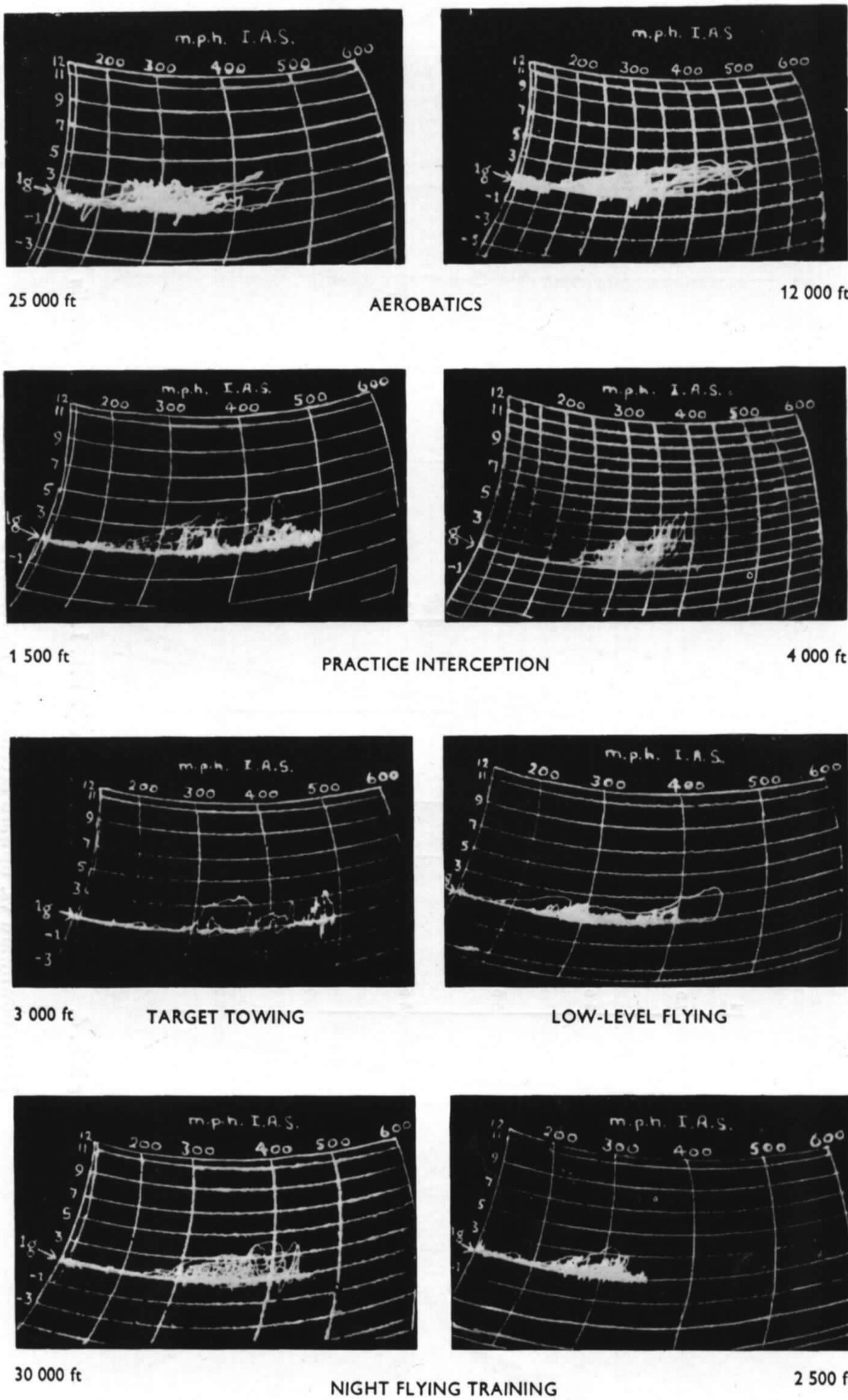


FIG. 2. Typical examples of V-g records from *Meteor* NF11 aircraft.

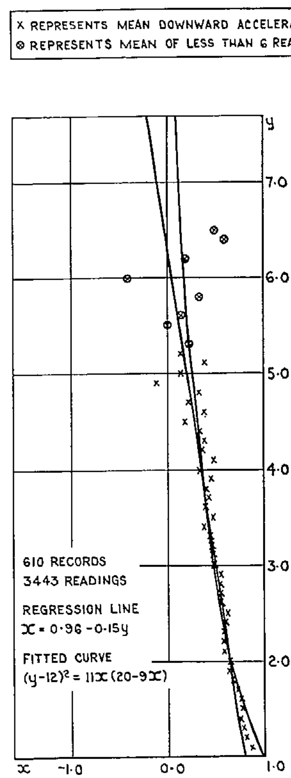


FIG. 3. *Hunter* Mk. 4.

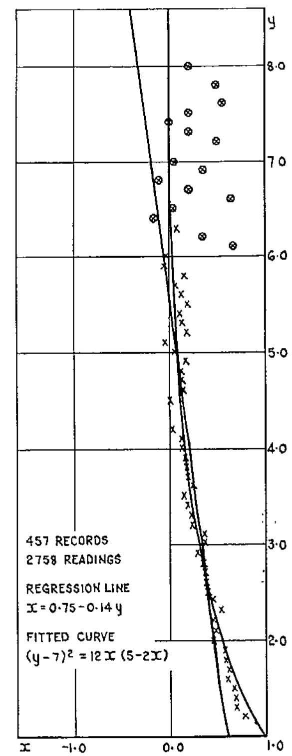


FIG. 4. *Swift* Mk. 1.

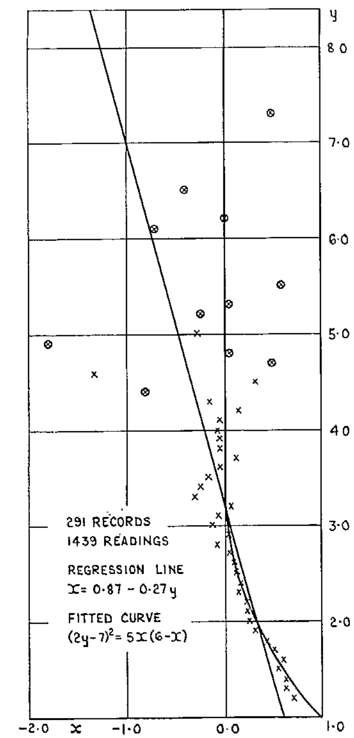


FIG. 5. *Javelin* Mk. 1.

Mean downward vs. upward acceleration, regression line and fitted curve.

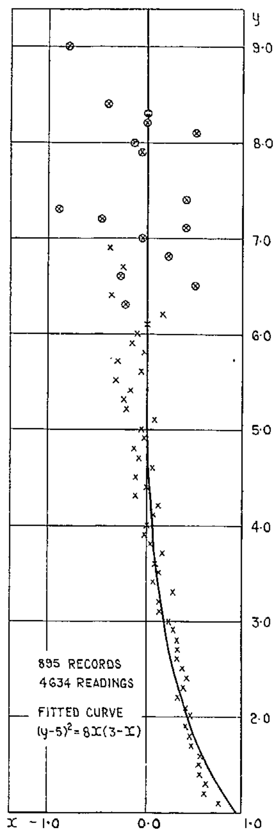


FIG. 6. *Meteor* Mk. 8.

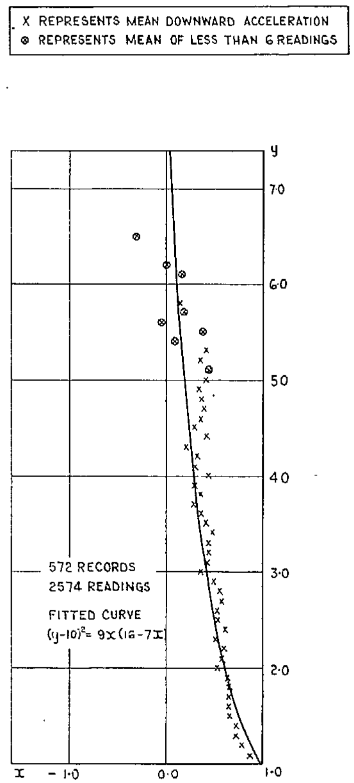


FIG. 7. *Meteor* NF11.

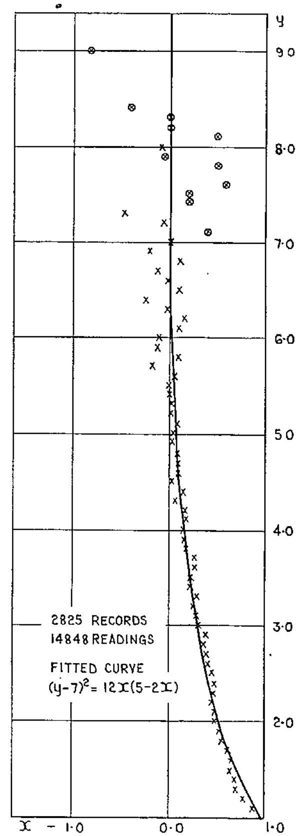


FIG. 8. Total R.A.F. Fighters.

Mean downward vs. upward acceleration and fitted curve.

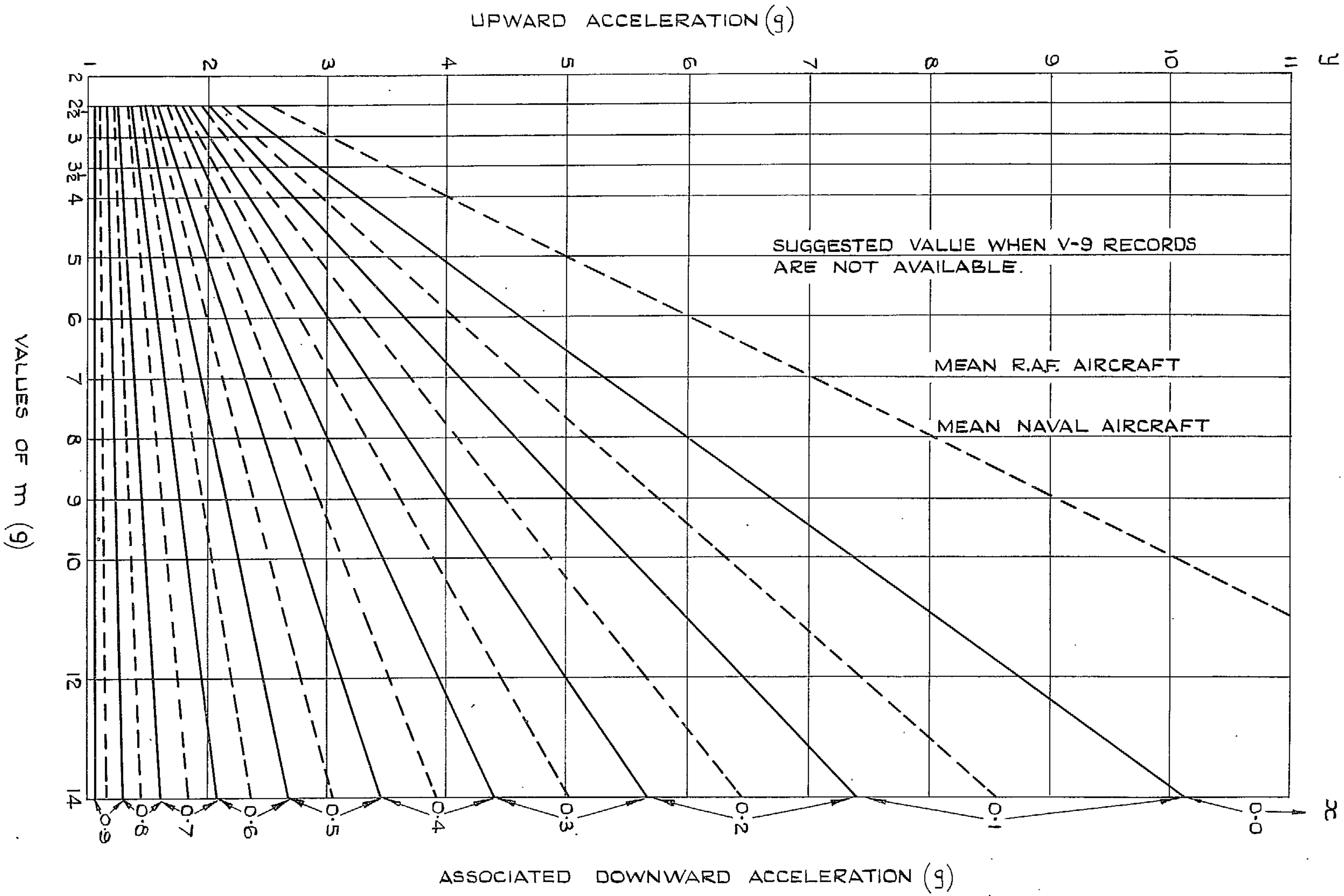


FIG. 9. Diagram showing the downward acceleration (x) associated with any upward acceleration (y) for all values of m from $2\frac{1}{2}$ to 14, using the equation $(y-m)^2 = (m-1)\,x\,[2(m-2) - x(m-3)]$.

x REPRESENTS MEAN DOWNWARD ACCELERATION

⊗ REPRESENTS MEAN OF LESS THAN 6 READINGS

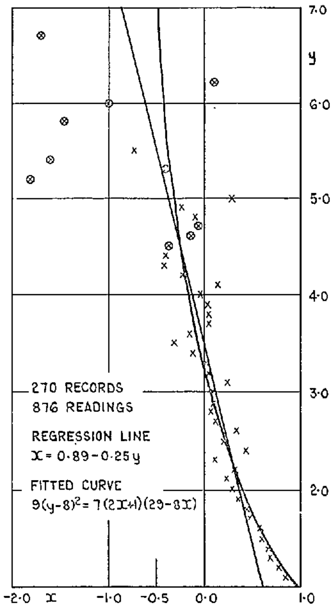


Fig. 10. *Jet Provost* Mk. 1 —Aerobatics.

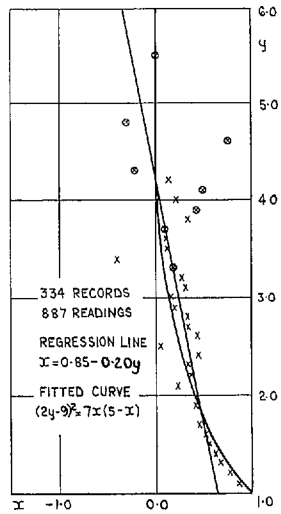


Fig. 11. *Jet Provost* Mk. 1—Other Duties.

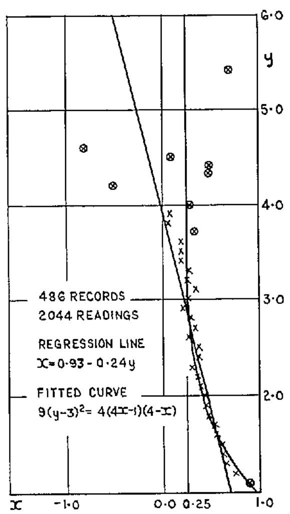


Fig. 12. *Canberra* B8.

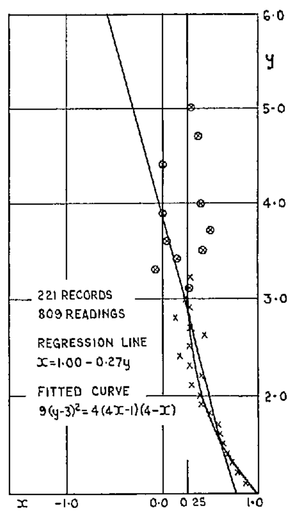


Fig. 13. *Gannet* A/S Mk. 1.

Mean downward vs. upward acceleration, regression line and fitted curve.

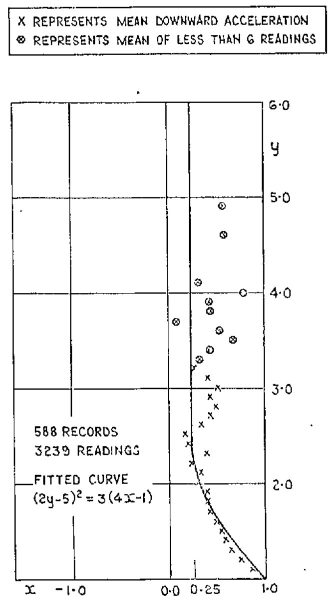


FIG. 14. *Canberra* B2 —Operational.

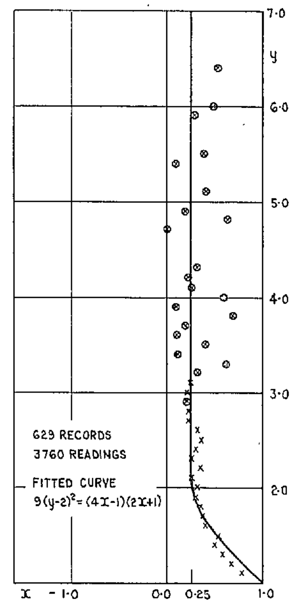


FIG. 15. *Canberra* B2 —Training.

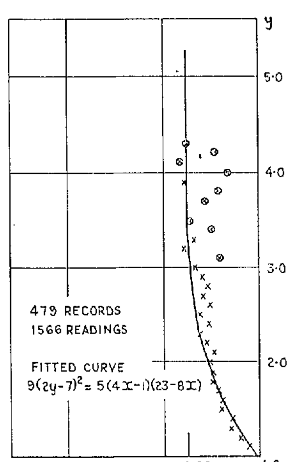


FIG. 16. *Canberra* B6 (excluding Ground Attack).

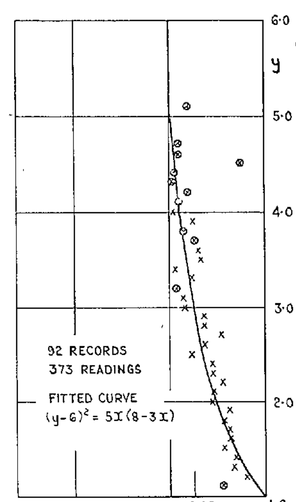


FIG. 17. *Canberra* B6 —Ground Attack.

Mean downward vs. upward acceleration and fitted curve.

(89799) Wt. 65/1418 K.5 7/64 Hw.

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