C.P. No. 878

C.P. No. 878

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Comparison of Helicopter and Aeroplane Vertical Accelerations in Turbulence

by

D. A, Webber, B.Sc.

LONDON: HER MAJESTY'S STATIONERY OFFICE

1966

PRICE 6*s* 6*d* NET

U.D.C. No. 533.6.048.5 : 531.113 : 533.661 : 533.65 : 551.511.6

C.P. No. 878

August 1965

COMPARISON OF HELICOPTER AND AEROPLANE VERTICAL ACCELERATIONS IN TURBULENCE

by

D. A. Webber, B.Sc.

SUMMARY

Counts of acceleration increments were recorded in a helicopter and an aeroplane flying through the same weather. The accelerations were compared and values for the gust alleviation factor for the helicopter were deduced. It is shown that these values increase with forward speed and at the highest forward speed attained are in reasonable agreement with the American MIL-S-8698 requirements.

Replaces R.A.E. Technical Report No.65190 - A.R.C. 27417

CONTENTS

1 INTRODUCTION

The tests described in this report were initiated when the gust case for the helicopter was receiving serious attention; although much of the airframe was designed by the emergency landing and flight manoeuvre cases, the design of many components was dictated by the gust case which specifies an arbitrary gust alleviation factor, unsupported by experimental data.

The simplified treatment has so far been adequate for design purposes, but further work is needed to substantiate the requirements. A preliminary approach has been made by flying a helicopter and an aeroplane through nominally the same weather and a comparison made of the acceleration responses. The gust alleviation factor for the aeroplane has been fairly well established[1,2] and the factors for the helicopter have been deduced using the ratio of the responses and this factor as a measure of the gust input.

The results of this investigation and a brief comparison with current design requirements are presented in this report.

2 DESCRIPTION OF TESTS

Two helicopters, a Whirlwind and a Sycamore, were used for the tests and the accompanying aircraft in each case, from which the gust input was deduced, was a Chipmunk.

Acceleration counts were recorded over ten minute periods, each period consisting of a straight and level flight at nominally constant forward speed, rotor speed, height and weight. The effect of varying these parameters during successive ten minute periods was not fully explored on the Whirlwind but sufficient information was obtained to show that the effect of the available weight variation was negligible. The experiment was continued with the Sycamore, this time repeating each ten minute run, first with the Sycamore leading and then with the Chipmunk leading. It was appreciated that close formation flying might lead to control-induced accelerations by the pilot attempting to maintain formation and the pilots were asked to make as few control corrections as possible.

From examination of the data at the completion of those tests it was evident that the samples being compared were too small for reliable responses to be calculated. It was decided to obtain a better appreciation of the effect of forward speed at the expense of further investigation of variations in weight and rotor speed, and the final tests were made with the aircraft flying in echelon at least 200 ft apart to avoid possible control induced accelerations mentioned above.

Details of the instrumentation and the range of tests are given in Appendix A.

3 RESULTS

The total acceleration counts at each increment of g obtained for each set of flight parameters are shown in Tables 2, 3 and 4 and a typical plot of acceleration against the number of counts is shown in Fig.1.

Runs at the two lower rotor speeds of the Whirlwind produced few acceleration counts and for the subsequent analysis the data for all rotor speeds were combined and are given in Table 5. Counts at equal increments of g above and below the 1g flight level have been combined following normal practice in gust analysis.

The acceleration counts for the first series of Sycamore-Chipmunk tests were also insufficient to show any variations that might be due to formation order or different rotor speeds and the combined acceleration counts are given in Table 6. The acceleration counts for the second series of Sycamore-Chipmunk tests are given in Table 7. Tables 5, 6 and 7 have also been reproduced as numbers of counts per mile v incremental acceleration in Figs.2, 3 and 4. The response ratios (Appendix B) for all tests are shown in Fig.5.

The gust alleviation factors for the helicopters were calculated from the response ratios and the gust alleviation factor for the Chipmunk. The method of analysis is given in Appendix B. These are shown in Fig.6 together with the factors obtained from a theoretical evaluation[3].

Possible errors in the derivation of the response ratio have been considered, particularly in the light of recent work at R.A.E., both theoretical[4] and experimental, on power spectral analysis of turbulence. These errors, however, would only become critical if there were such large differences between the response characteristics of the various aircraft considered, that the intersections of their $\Delta'n$ - N curves with the N-axis occurred at widely different frequencies. Examination of these curves shows that the intersections are fairly close together and gives confidence in the method of analysis.

The gust alleviation factors, although showing some divergence at the lower forward speeds, indicate that the alleviation decreases with increasing speed. This effect is also shown by the theoretical calculation[3] and although these results were stated to be conservative, the gust alleviation factors were considerably higher than those deduced in this exercise.

At the highest forward speed attained, the deduced factors are about 0.60 for the Whirlwind and 0.55 for the Sycamore. These are in reasonable agreement with those of the American Military Specification, MIL-S-8698 (Appendix C.1), which would specify 0.70 and 0.61 respectively for the two helicopters in association with a gust velocity of 50 ft/sec. The American Federal Aviation Regulations (Appendix C.2) specify a gust velocity of 30 ft/sec, but with no alleviation factor. If the measured alleviation factor for the Sycamore is taken into account, the Federal Aviation Regulations would imply a gust intensity of 54 ft/sec. The British Civil Airworthiness Requirements would be even more conservative for this helicopter.

4 CONCLUSIONS

The analyses of the experimental measurements indicate that gust alleviation factors of about 0.60 and 0.55 were obtained for the Whirlwind and Sycamore helicopters There was insufficient data available for investigating the influence of rotor speeds but the measurements show that the alleviation factor increases with forward speed of the helicopter. The deduced factors agree reasonably well with those in the American Specification MIL-S-8698.

It would appear that the British Civil Airworthiness Requirements demand a higher strength in the gust case for these particular helicopters than do the American Requirements.

Appendix A

A.1 Instrumentation

The helicopter and the aeroplane were each fitted with a counting accelerometer near the cg of the aircraft. Acceleration thresholds were displayed on a visual counter unit in 0.05g steps from 0.5g to 1.5g absolute in the helicopter and were recorded, at the beginning and end of each ten minute run, by an auto-observer in 0.1g steps from 0g to 2g absolute in the Chipmunk.

A.2 Range of tests

(1) Whirlwind-Chipmunk

Forward speed:	50, 70 and 80 knots
Rotor speed:	185, 192 and 198 rev/min
Rotor blade radius:	26.5 ft
Weight of Whirlwind:	from 6000 lb (minimum fuel and two crew) to 7400 lb (maximum fuel and four crew)
Weight of Chipmunk:	1850 lb (take-off weight)
Height:	1000 ft approx

Duration of acceleration records obtained: 8 hr 50 min

(2) Sycamore-Chipmunk, first series

Forward speed:	50, 70 and 80 knots
Rotor speed:	240, 250 and 260 rev/min
Rotor blade radius:	24.3 ft
Weight of Sycamore:	4850 lb (take-off weight)
Weight of Chipmunk:	1864 lb (take-off weight)
Height:	1000 ft approx

Duration of acceleration records obtained: 13 hr 20 min

(3) Sycamore-Chipmunk, second series

Forward speed:	50, 60, 70 and 80 knots
Rotor speed:	250 rev/min
Weight of Sycamore:	4850 lb (take-off weight)
Weight of Chipmunk:	1864 lb (take-off weight)
Height:	1000 ft approx

Duration of acceleration records obtained: 24 hr 20 min

Appendix B

B.1 Method of analysis

In these tests the aeroplane is being used to measure the vertical gust velocity experienced by both the aeroplane and the helicopter. The discrete gust theory approach, given in Av.P.970 (Ref.1) is used to calculate the gust alleviation factor (F_A) for the aeroplane.

The response of the aeroplane (Δn_A) can be calculated for a given gust velocity (U) by assuming that there is an instantaneous change of lift due to the gust and that it experiences no change of attitude or forward speed:

$$\Delta n_A = \tfrac{1}{2}\rho\, UVSa/W_A \tag{B1}$$

$$(\Delta n_A = 0.000495\ UV \text{ for the Chipmunk})$$

An observed response of the aeroplane ($\Delta' n_A$) can be converted to the gust velocity (U) since by definition:

$$\Delta' n_A = F_A\, \Delta n_A \tag{B2}$$

The response of the helicopter (Δn_H) can be calculated for the same gust (U)[5]:

$$\Delta n_H = \tfrac{1}{4}\rho\, \Omega\, b\, c\, a\ UR^2/W_H\ (1 + b\,c\,a/8\pi\, R\mu) \quad \mu > 0.1 \tag{B3}$$

$$(\Delta n_H = 0.03496\ UV/(V + 19.28) \text{ for the Sycamore}$$

$$\Delta n_H = 0.02765\ UV/(V + 18.42) \text{ for the Whirlwind})$$

An observed response of the helicopter can also be expressed as:

$$\Delta' n_H = F_H\, \Delta n_H \tag{B4}$$

where F_H is the gust alleviation factor for the helicopter. Combination of equations (B2) and (B4) gives:

$$F_H = F_A \frac{\Delta n_A}{\Delta n_H} \Bigg/ \frac{\Delta' n_A}{\Delta' n_H} \tag{B5}$$

where $\Delta' n_A/\Delta' n_H$ is the experimental ratio of the acceleration responses.

The two aircraft cannot experience identical gusts and therefore the ratio $\Delta' n_A / \Delta' n_H$ cannot be calculated directly from a single gust encounter. However, over a period of time it is assumed that if both aircraft fly close together they will both experience the same overall gust pattern.

It is shown in Appendix B.2 that if the incremental acceleration response of the aircraft is plotted against the number of counts at that increment, the slope of the line obtained gives a measure of the response of the aircraft, and the ratio of the slopes for the aeroplane and the helicopter will be the response ratio $\Delta' n_A / \Delta' n_H$.

The slopes were calculated directly from the acceleration counts for a preliminary analysis, but this method was inaccurate where there were few g increments and the response ratios shown in Fig.5 were obtained from graphs of acceleration v numbers of counts.

B.2 Evaluation of the response ratio from normal accelerations and frequencies of occurrence

(1) The experimental curve of N against $\Delta' n$ is of exponential form and can be expressed as:

$$N = N_o \exp(-\Delta' n/p) \text{ where p is a constant.} \tag{B6}$$

If the value of N_o is the same for both helicopter and aeroplane, then for any chosen value of N:

$$\underline{\Delta' n_H / \Delta' n_A = p_H / p_A} \quad . \tag{B7}$$

From equation (B6),

$$\log N = -\Delta' n/p + \log N_o$$

hence:

$$\log N_S - \log N_{S-1} = (\Delta' n_{S-1} - \Delta' n_S)/p \; . \tag{B8}$$

Since $\Delta' n_A$ decreases by equal increments of 0.1g and $\Delta' n_H$ decreases by equal increments of 0.05g, then:

$$p_A = 0.1/\log(N_S/N_{S-1})_A \tag{B9}$$

$$p_H = 0.05/\log(N_S/N_{S-1})_H \qquad \text{(B10)}$$

(2) <u>Common ratio</u>

From equation (B6) the acceleration counts form a geometrical progression:

$$N_S/N_{S-1} = R \text{ where R is the common ratio} \qquad \text{(B11)}$$

From equations (B7), (B9), (B10) and (B11)

$$\Delta' n_H/\Delta' n_A = \tfrac{1}{2} \log R_A/\log R_H \qquad \text{(B12)}$$

As the acceleration counts, in practice, approximate to a geometrical progression the common ratio can be expressed as:

$$R = \sum_1^S N \sum_1^{S-1} N \qquad \text{(B13)}$$

Appendix C

SUMMARY OF KNOWN SOURCES FOR THE GUST CASE FOR HELICOPTERS

1 Structural Design Requirements, Helicopters MIL-S-8698 (ASG) Amended 1958

Airspeed shall be V_H in forward flight. A gust of 50 ft/sec shall be encountered. Gust alleviation factors shall be determined from a graph of the factors plotted against disc loading.

Typical values are 2 lb/sq ft - 0.51, 3 lb/sq ft - 0.63, 4 lb/sq ft - 0.79, 6 lb/sq ft - 1.00.

2 Federal Aviation Regulations, Part 29B, October 1964

Each rotorcraft must be designed to withstand, at each critical airspeed including hovering, the loads resulting from vertical and horizontal gusts of 30 ft/sec.

3 Air Registration Board. British Civil Airworthiness Requirements (Section G) January 1954, Issue 1

The rotorcraft is assumed to be flying in a trimmed unaccelerated flight condition corresponding to any point on or within the symmetric flight envelope and encounters a gust of velocity 35 ft/sec from any direction. The gust intensity shall be considered as sharp edged. The assumption is thus made of unit alleviation factor for this gust velocity.

4 Kaman Report R - 30 (P-72331) February 1957

This is a theoretical treatment involving physical and aerodynamic rotor blade constants. The alleviation factor is given in a family of carpet graphs in which the parameters are the ratio of blade mass to aircraft mass, ratio of forward speed to blade tip speed, number of blades and Lock's inertia number ($\rho a c R^4/I$). The blade is assumed of a uniform mass and constant chord and of zero twist. Results are given assuming a sharp edged gust and may be taken as being conservative.

Table 1a

RECORDED FLYING TIME - WHIRLWIND-CHIPMUNK
(Time in minutes at each parameter)

Forward speed knots	Rotor speed rev/min		
	185	192	198
50	20	40	100
70	40	80	100
80	10	40	100

Table 1b

RECORDED FLYING TIME - SYCAMORE-CHIPMUNK, 1st SERIES
(Time in minutes at each parameter, both formation orders combined)

Forward speed knots	Rotor speed rev/min		
	240	250	260
50	100	100	100
70	100	120	100
80	-	100	80

Table 1c

RECORDED FLYING TIME - SYCAMORE-CHIPMUNK, 2nd SERIES
(Time in minutes at each forward speed. Rotor speed 250 rev/min)

Forward speed knots			
50	60	70	80
350	360	380	370

Table 2

ACCELERATION COUNTS WHIRLWIND-CHIPMUNK (Chipmunk leading)

Forward speed (knots)	Rotor speed rev/min	Whirlwind response (g)												Chipmunk response (g)																	
		0.65	0.7	0.75	0.8	0.85	0.9	1.1	1.15	1.2	1.25	1.3	1.35	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
50	185				1	5	40	74	21	2	1									3	8	33	33	3	1						
	192			1	1	6	53	94	16	2											5	32	59	9	1						
	198			2	15	93	369	446	132	29	13	3						1	2	44	35	201	362	72	19	5					
70	185				2	8	53	81	8	3	1									3	8	38	74	13	1						
	192			1	7	46	255	294	54	7									3	9	33	133	350	75	14	3	1				
	198			3	18	90	424	459	112	26	10	4					1	3	4	19	72	288	543	131	29	4	1				
80	185					4	53	61	8	2											1	9	35	5							
	192				2	20	146	127	19	6	2	1							1	2	10	51	111	22	6	1					
	198			8	53	199	691	668	201	48	7	2		1	2	2	2	6	31	62	170	614	969	329	112	48	15	6	5	1	

Table 3(a)

ACCELERATION COUNTS SYCAMORE-CHIPMUNK 1st Series (Chipmunk leading)

Forward speed (knots)	Rotor speed rev/min	Sycamore response (g)																Chipmunk response (g)																	
		0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
50	240				1	2	5	33	105	178	42	8	2												4	42	18								
	250					1	5	21	122	191	47	6	1												1	29	9	1							
	260					1	8	25	173	215	44	6													5	35	11	2							
70	240					5	20	81	307	372	110	27	7	1									1	7	30	117	66	21	5	1					
	250				1	6	23	96	374	410	108	34	14	5	1									1	23	124	62	12							
	260					10	35	158	814	899	202	81	21	6	2							1	1	4	27	115	75	13	4						
80	250					8	47	150	719	707	157	47	15	4	1	1	1						5	13	43	132	106	23	5	2	1	1	1	1	1
	260			1	2	13	58	259	1480	833	139	31	9									1	3	13	40	156	99	23	6						

Table 3(b)

ACCELERATION COUNTS SYCAMORE-CHIPMUNK 1st Series (Sycamore leading)

Forward speed (knots)	Rotor speed rev/min	Sycamore response (g)														Chipmunk response (g)																	
		0.6	0.65	0.7	0.75	0.8	0.85	0.9	1.1	1.15	1.2	1.25	1.3	1.35	1.4	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
50	240					3	20	87	154	27	6	1							1	1	1	2	17	89	26	4							
	250				1	4	20	106	159	41	3	1	1									1	8	82	32	2							
	260			1	1	4	23	155	188	42	3											3	16	81	41	4							
70	240				3	6	32	167	243	45	8	3										2	25	121	72	14	8	1					
	250				1	12	41	262	358	71	9	2							1	2	3	12	41	185	94	28	7	2	1				
	260		1	2	5	23	105	627	558	126	38	6	1	1						1	2	12	42	192	128	23	3	1					
80	250				6	28	98	497	501	91	23	4	2	1						1	2	8	51	212	127	31	3						
	260			1	5	17	119	813	720	93	19	3	1								4	11	30	144	108	25	7	3	1				

Table 4

ACCELERATION COUNTS SYCAMORE-CHIPMUNK 2nd Series

Forward speed (knots)	Rotor speed rev/min	Sycamore response (g)															Chipmunk response (g)																	
		0.6	0.65	0.7	0.75	0.8	0.85	0.9	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
50	250			1	4	31	176	886	1011	191	49	10	1							1	1	4	21	99	552	348	67	10	2	1				
60	250	1	2	7	25	80	327	1605	1678	420	113	32	7	3					2	2	7	19	61	235	989	807	196	46	11	3	2			
70	250			9	34	159	643	3071	3104	729	207	59	16	5	3	2				1	6	23	89	380	1490	1249	325	87	21	3	1			
80	250	2	4	16	54	206	910	4307	4999	1044	293	82	26	8	2				2	4	14	45	152	551	1976	1745	519	161	48	10	1			

Table 5

WHIRLWIND-CHIPMUNK RESPONSES (incremental g)

Forward speed (knots)	Total time (min)	Whirlwind response increments of g									Chipmunk response increments of g								
		0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
50	160	1076	273	50	17	3					720	132	28	7	1				
70	220	1566	318	63	15	4					1426	332	75	14	5	1			
80	150	1746	451	111	17	3					1789	537	182	81	21	8	7	3	1

Table 6

SYCAMORE-CHIPMUNK RESPONSES (incremental g) 1st Series

Forward speed (knots)	Total time (min)	Sycamore response increments of g									Chipmunk response increments of g								
		0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
50	300	1833	385	61	11	3					495	64	6	1	1	1			
70	320	5391	1175	316	83	16	5				1351	299	65	12	5	1			
80	200	6270	1106	270	63	10	3	1	1		1084	266	66	19	4	1	1	1	1

REFERENCES

No.	Author	Title, etc.
1	-	Av.P.970 Leaflet 203/2, August 1959
2	J.K. Zbrozck	Gust alleviation factor. A.R.C. R & M 2970, August 1953
3	A. Berman	Dynamic response of a helicopter to a gust. Part II Kaman Report R-30, February 1957
4	J.K. Zbrozek	The relationship between the discrete gust and power spectra presentation of atmospheric turbulence, with a suggested model of low altitude turbulence. A.R.C. R & M 3216
5	A.R.S. Bramwell	Longitudinal stability and control of the single-rotor helicopter. A.R.C. R & M 3104

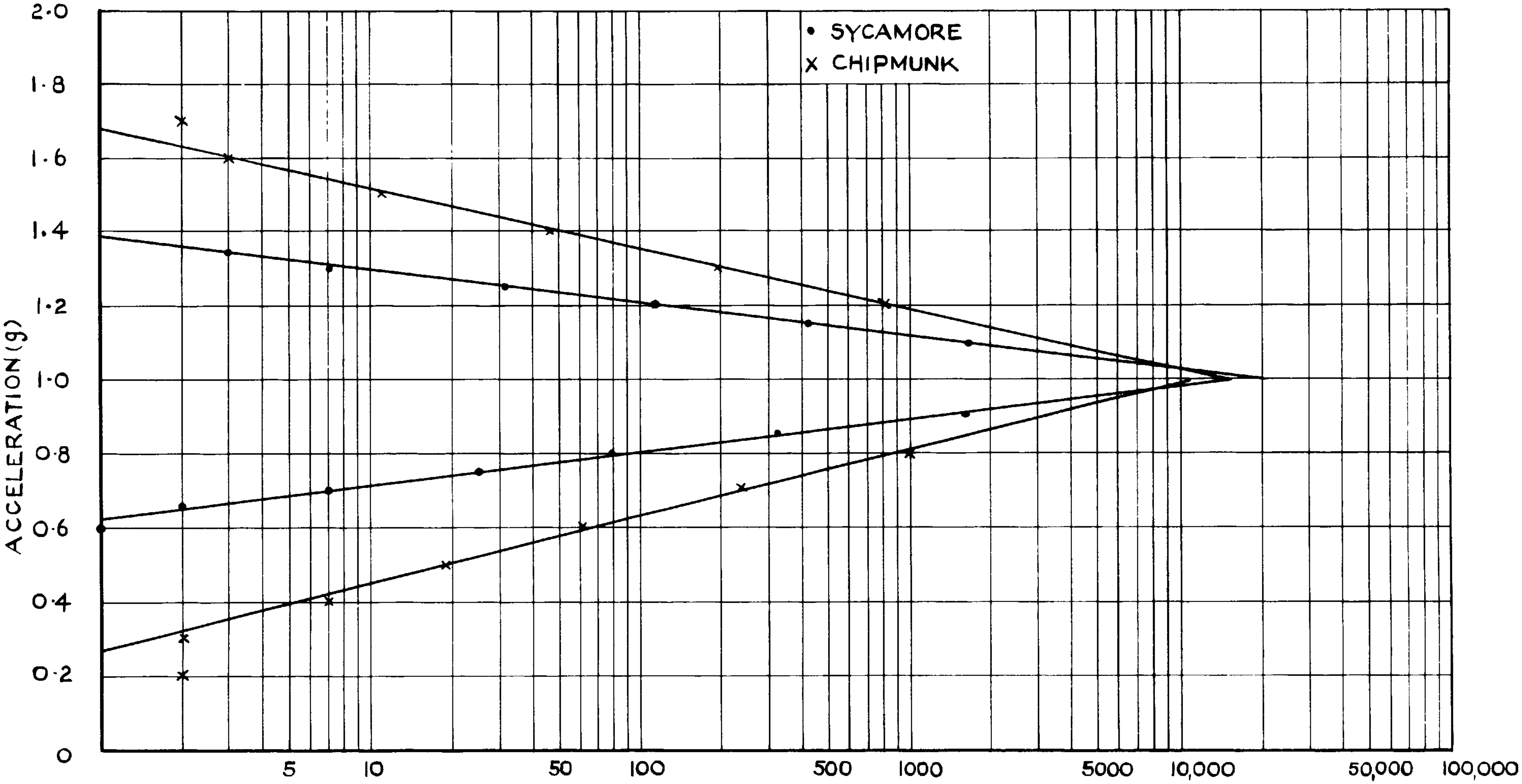

FIG. I SYCAMORE-CHIPMUNK 2nd SERIES NUMBER OF COUNTS v ACCELERATION

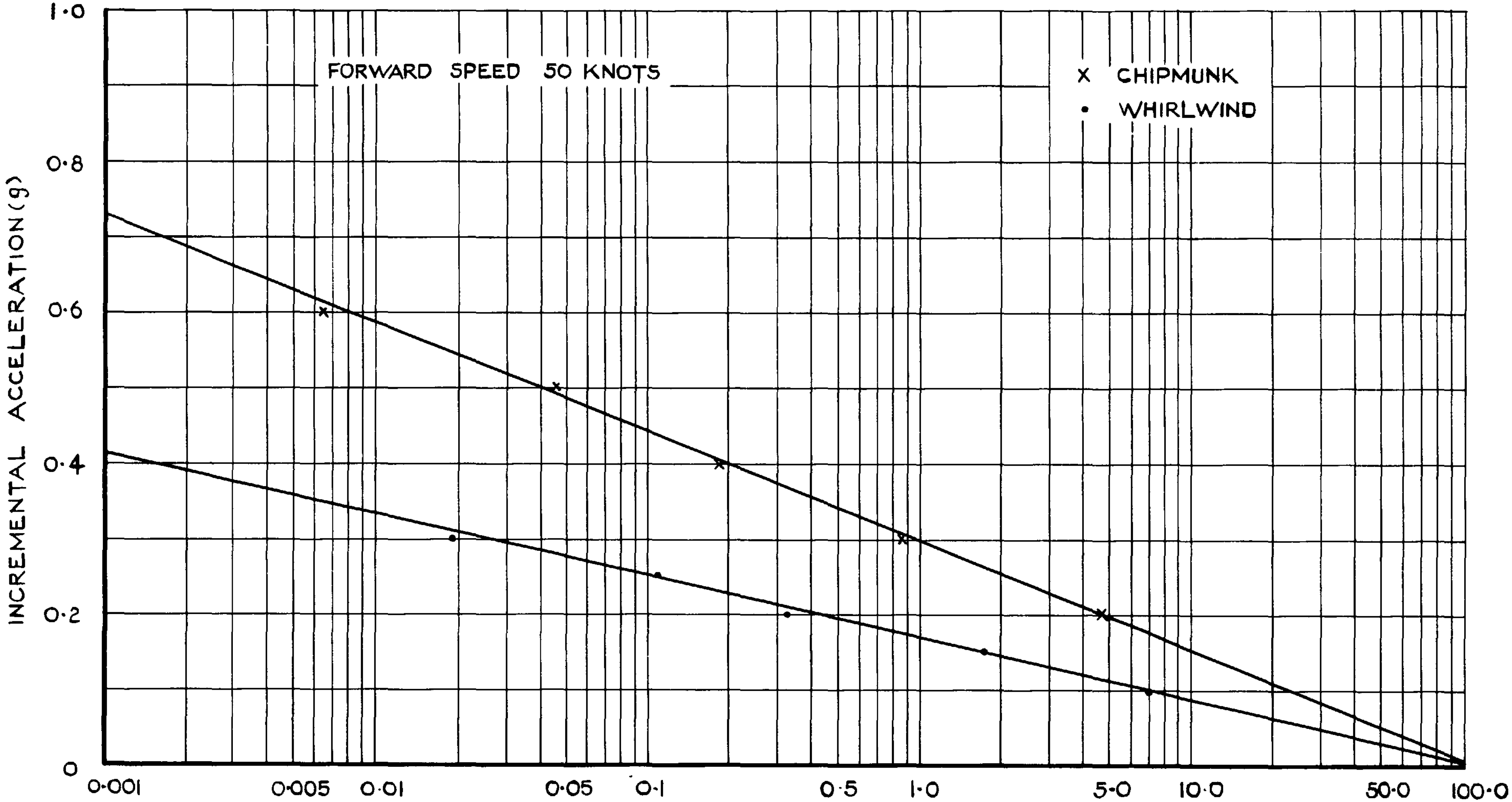

FIG. 2(a) WHIRLWIND-CHIPMUNK NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

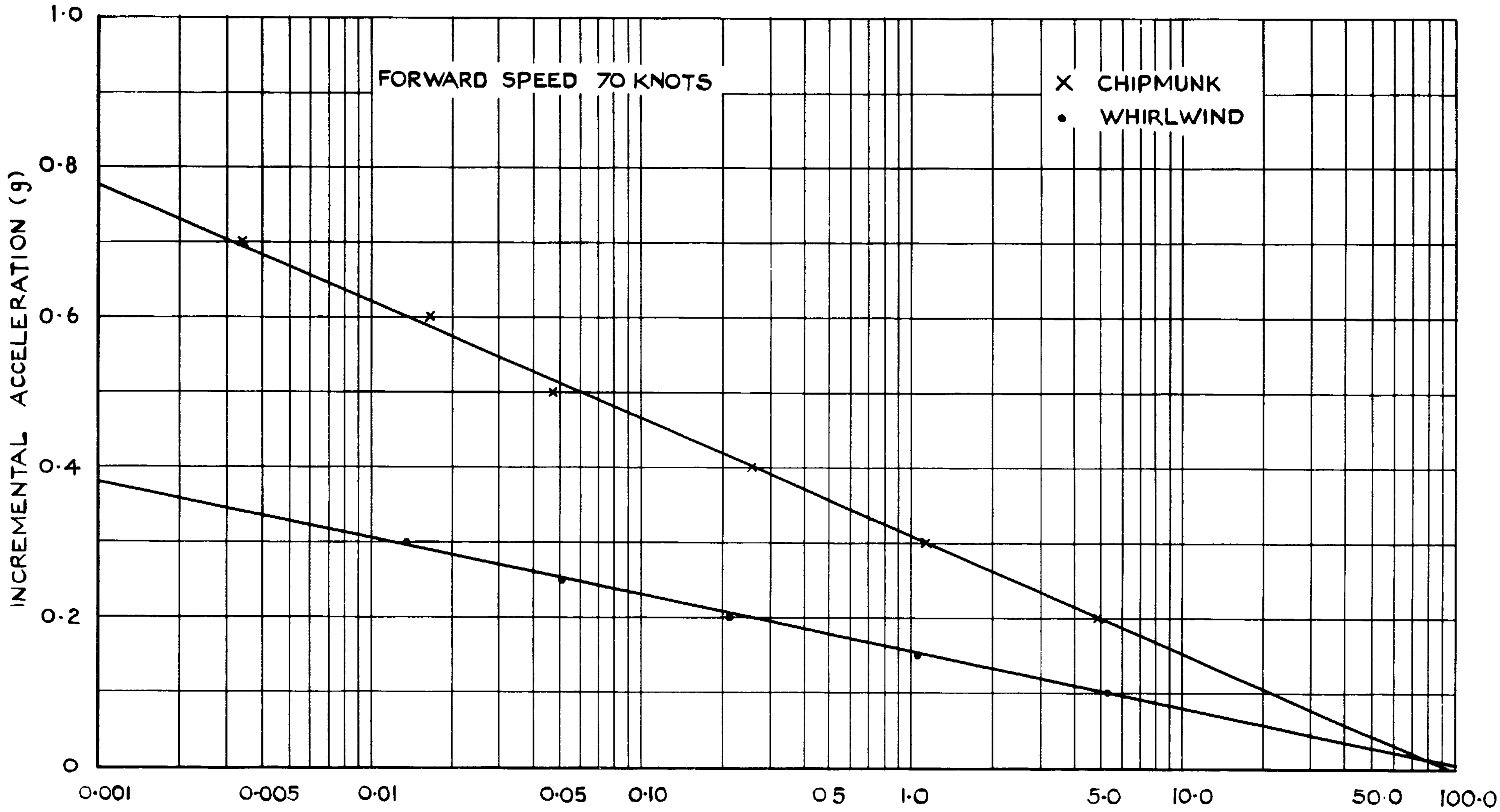

FIG. 2(b) WHIRLWIND–CHIPMUNK NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

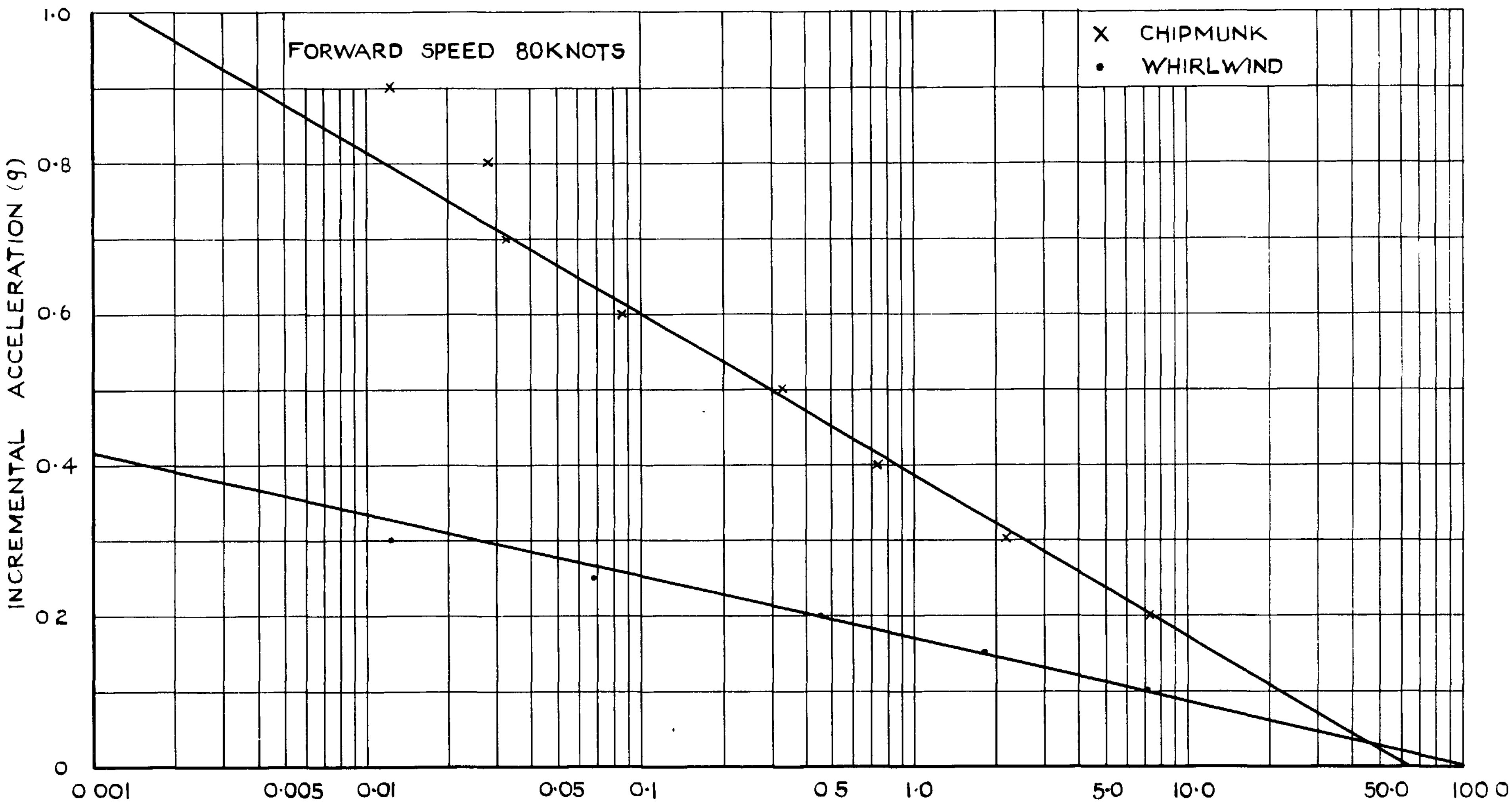

FIG. 2(c) WHIRLWIND CHIPMUNK – NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

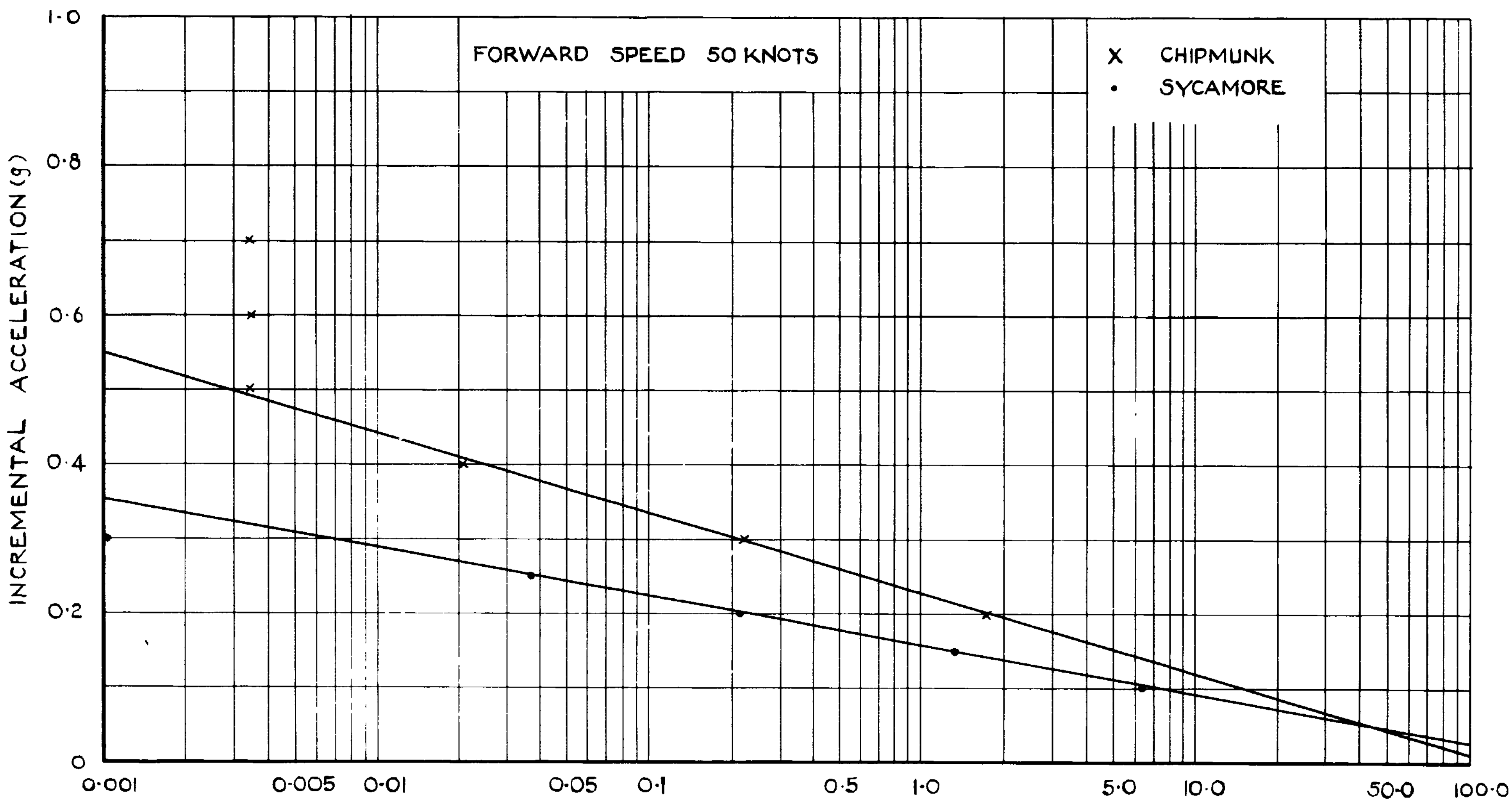

FIG. 3(a) SYCAMORE – CHIPMUNK 1st SERIES
NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

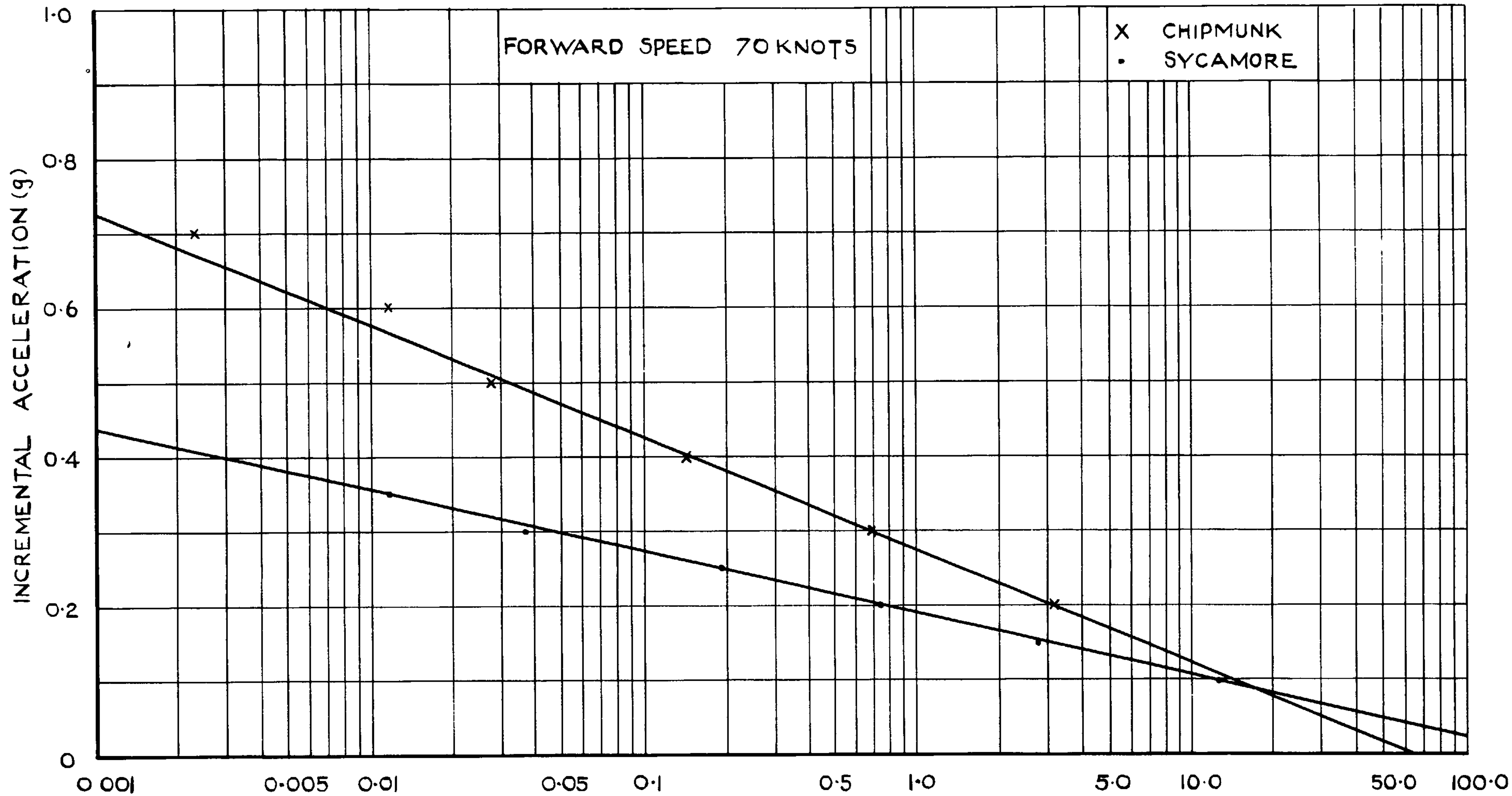

FIG. 3(b) SYCAMORE – CHIPMUNK 1st SERIES
NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

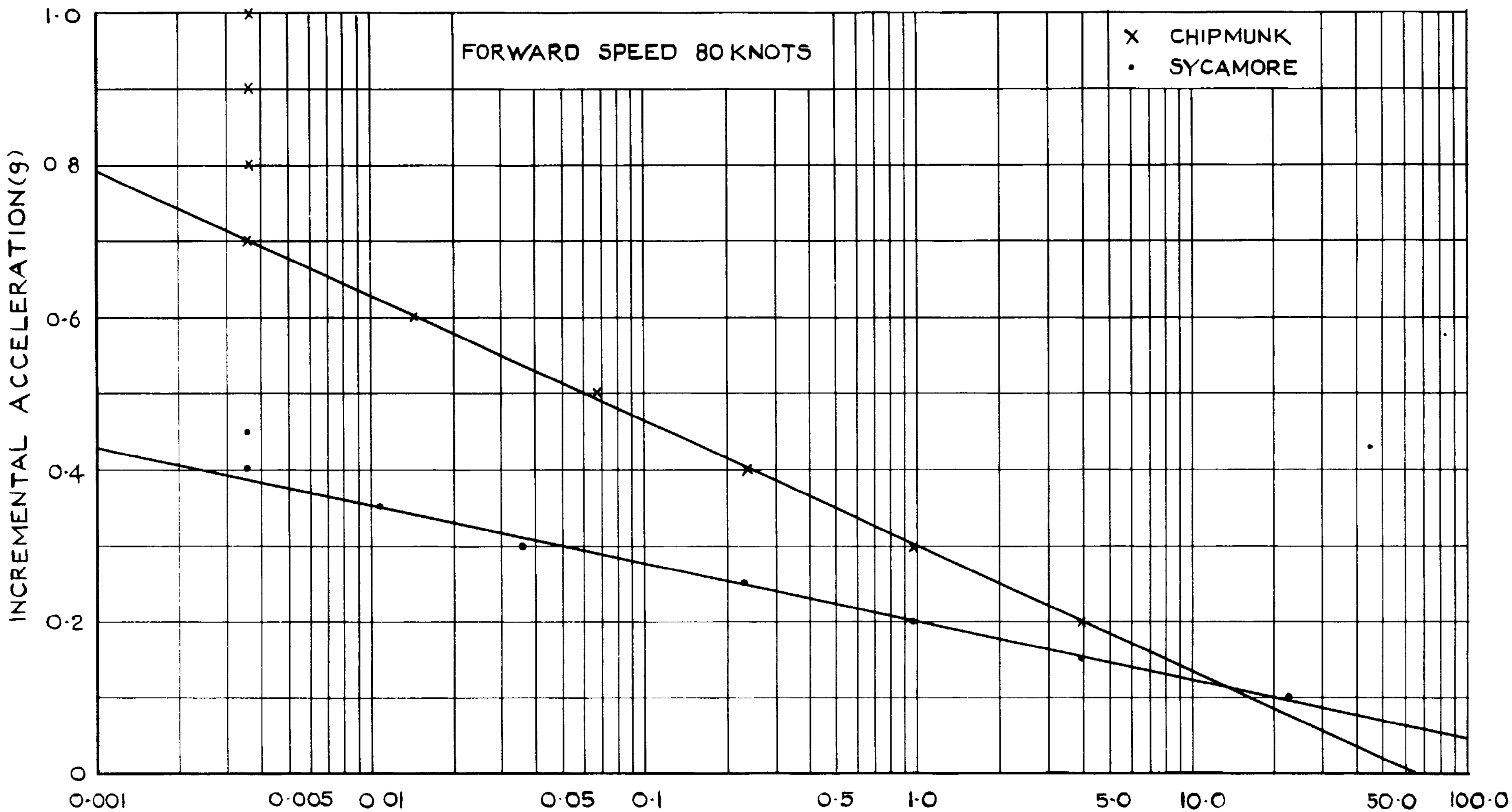

FIG. 3(c) SYCAMORE — CHIPMUNK 1st SERIES
NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

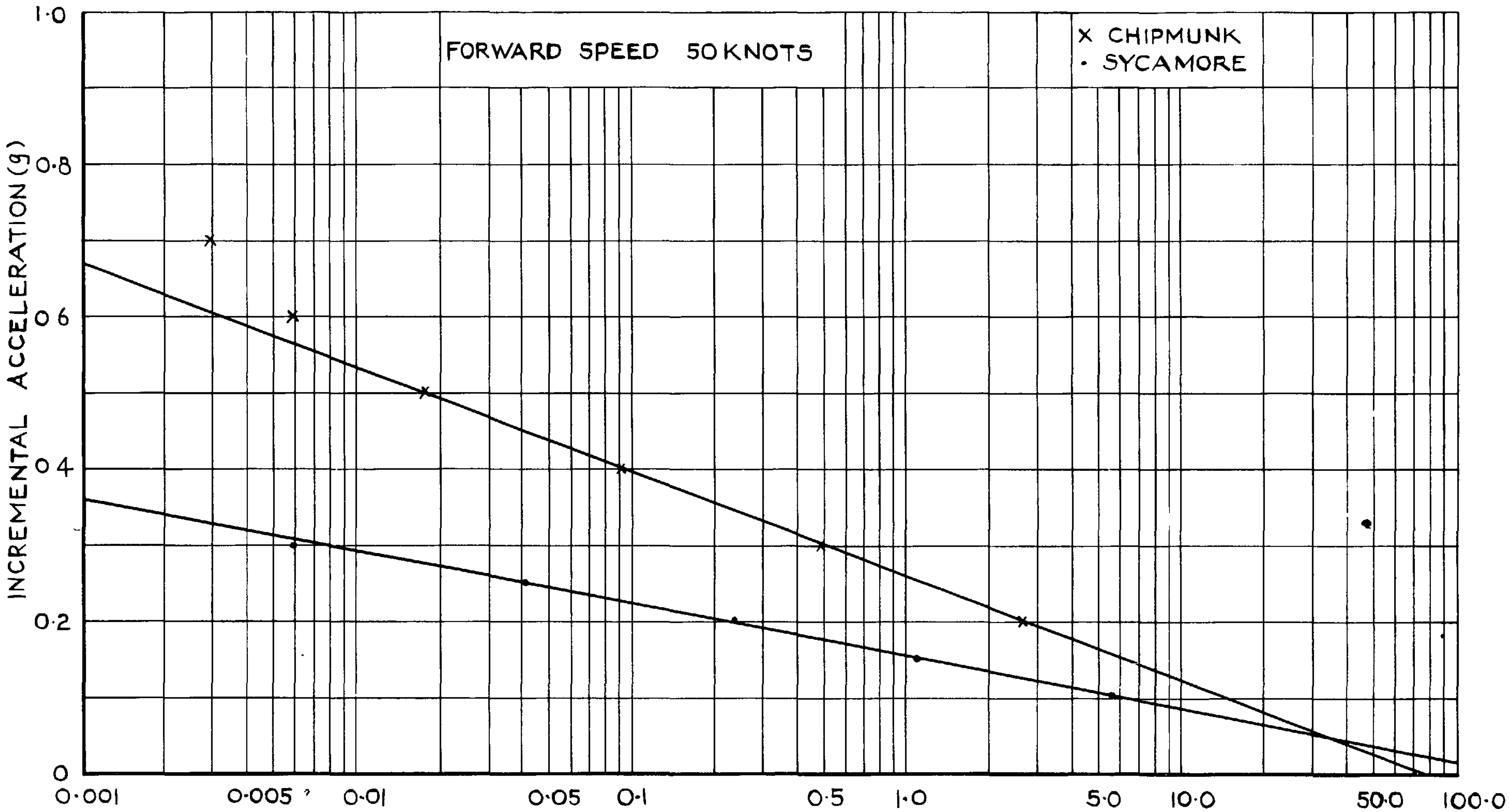

FIG. 4(a) SYCAMORE — CHIPMUNK 2nd SERIES
NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

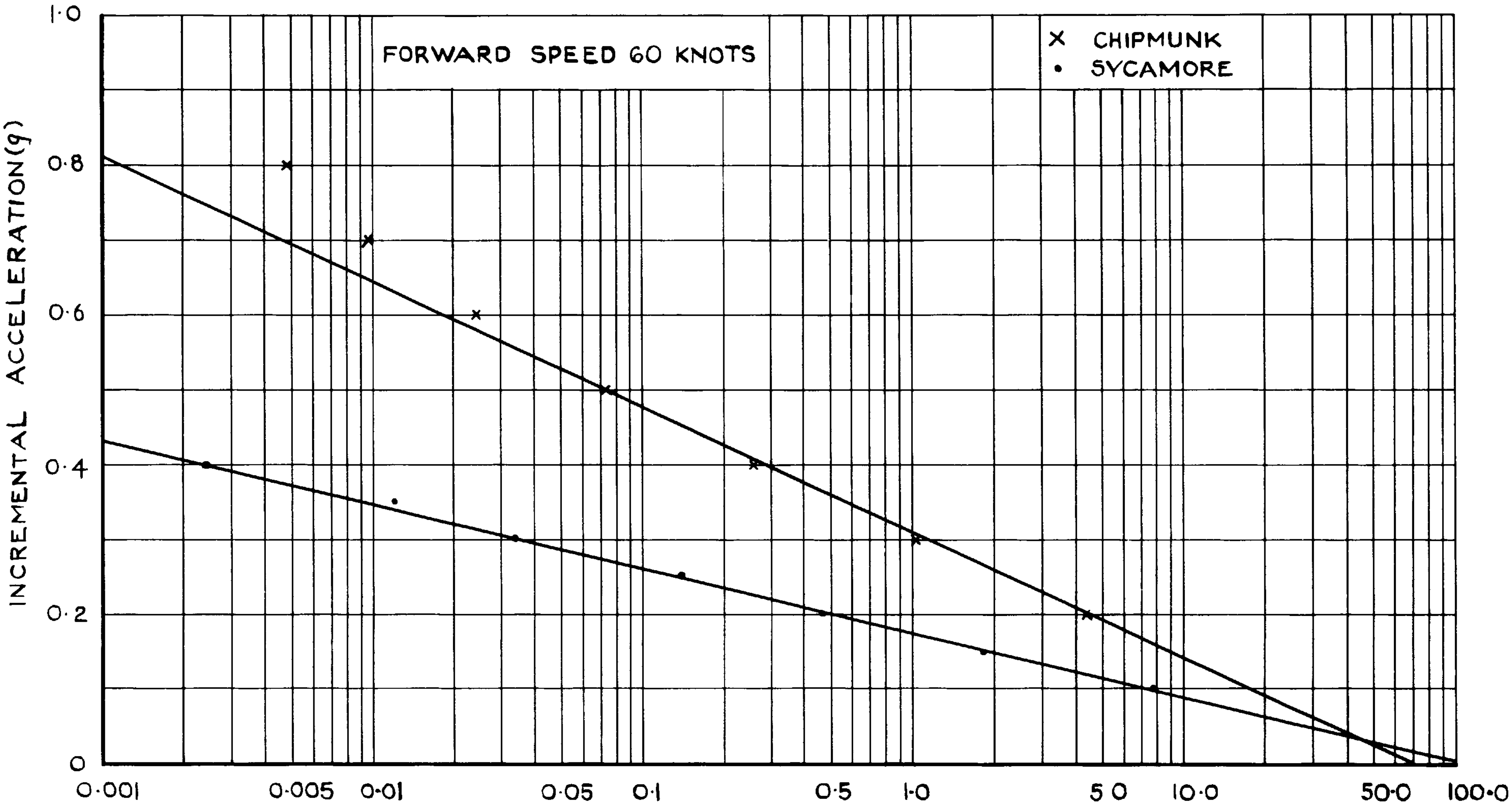

FIG. 4(b) SYCAMORE – CHIPMUNK 2nd SERIES
NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

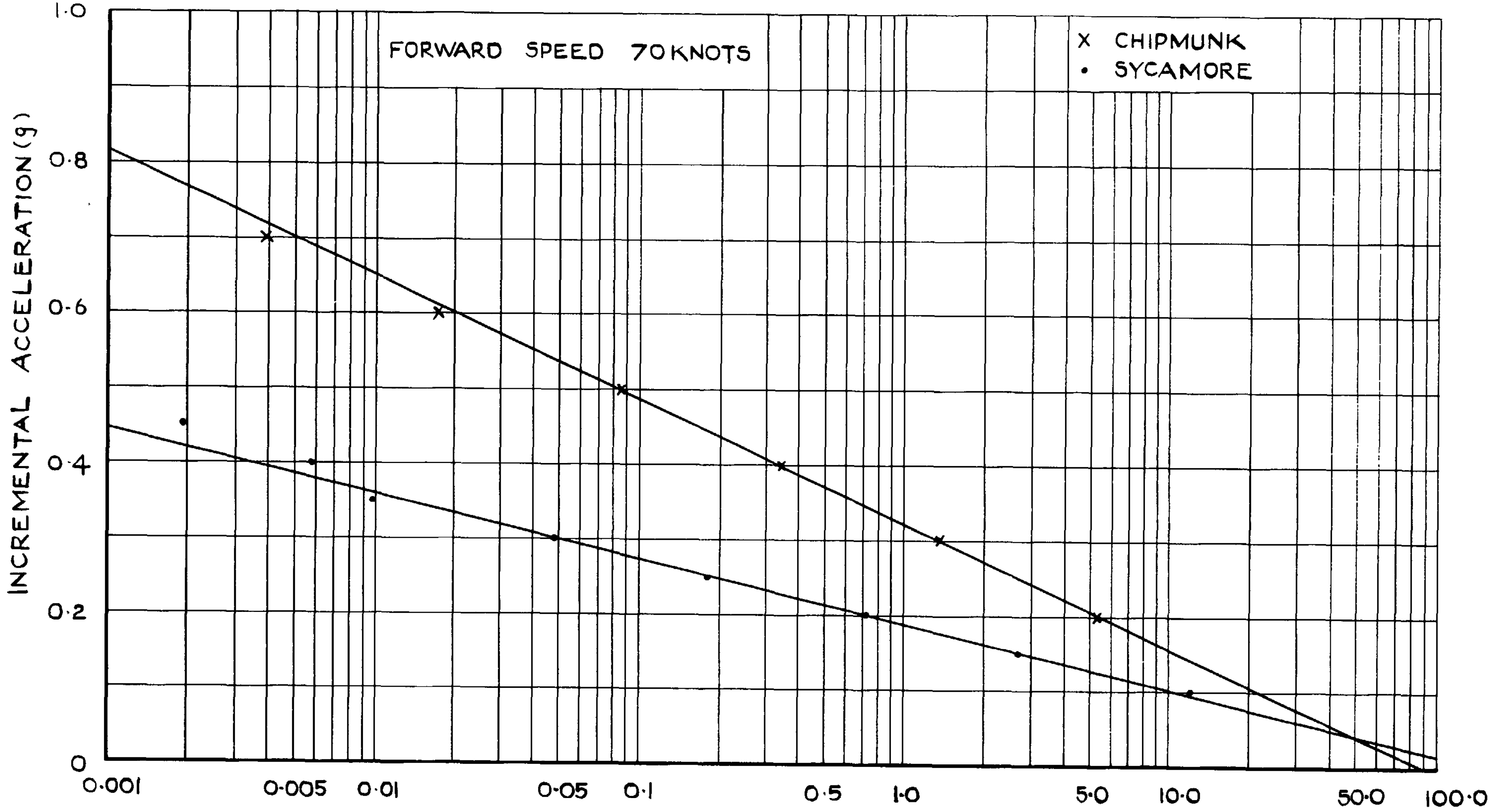

FIG. 4(c) SYCAMORE — CHIPMUNK 2nd SERIES
NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

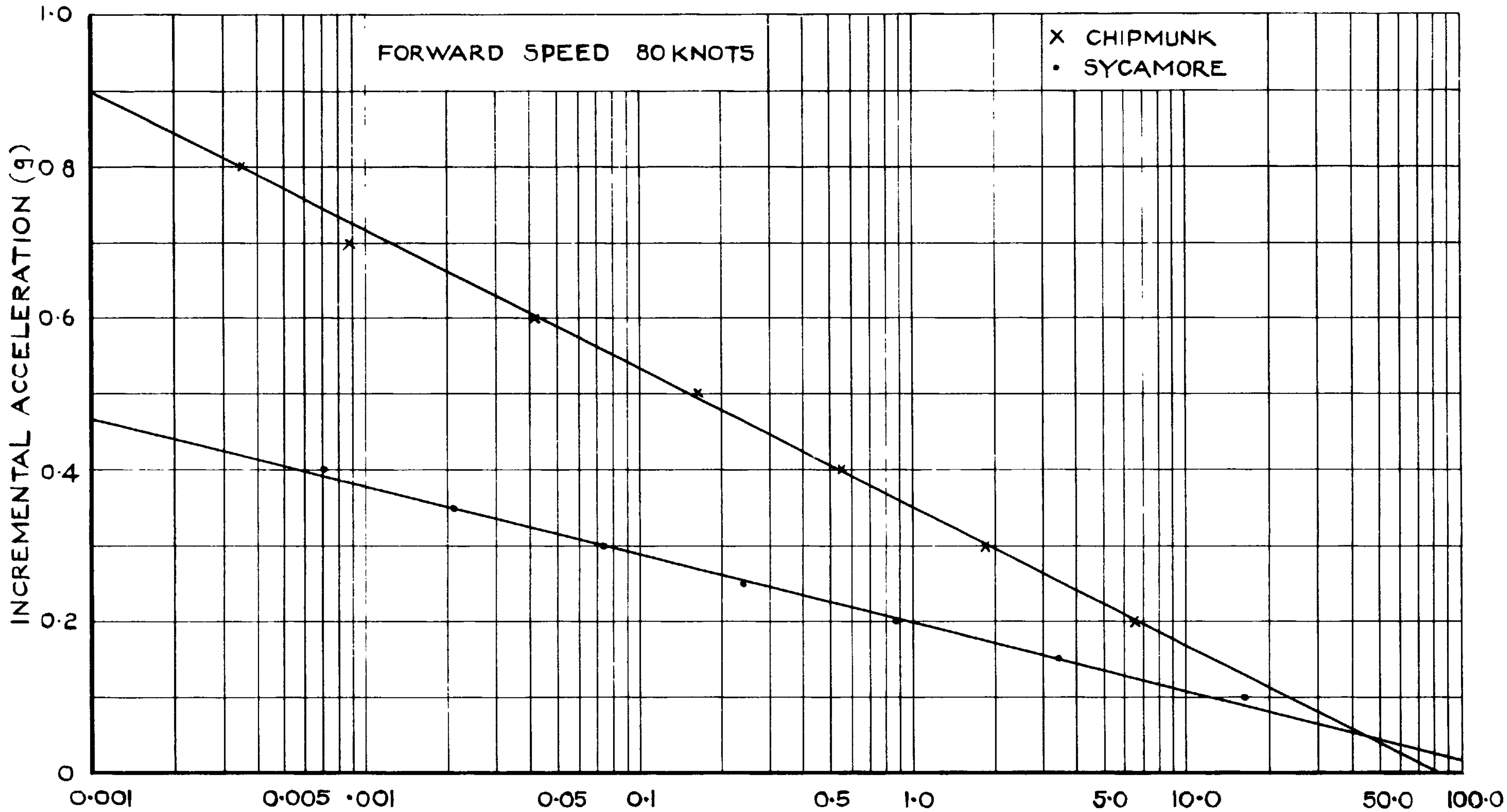

FIG. 4(d) SYCAMORE – CHIPMUNK 2nd SERIES
NUMBER OF COUNTS PER MILE v INCREMENTAL ACCELERATION

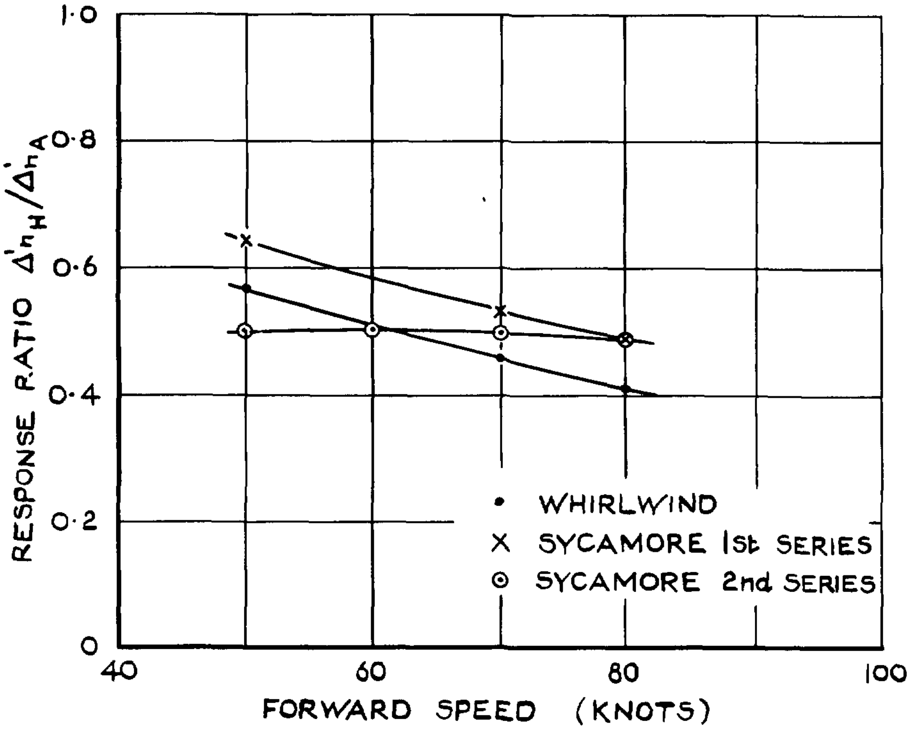

FIG. 5 RESPONSE RATIO v FORWARD SPEED

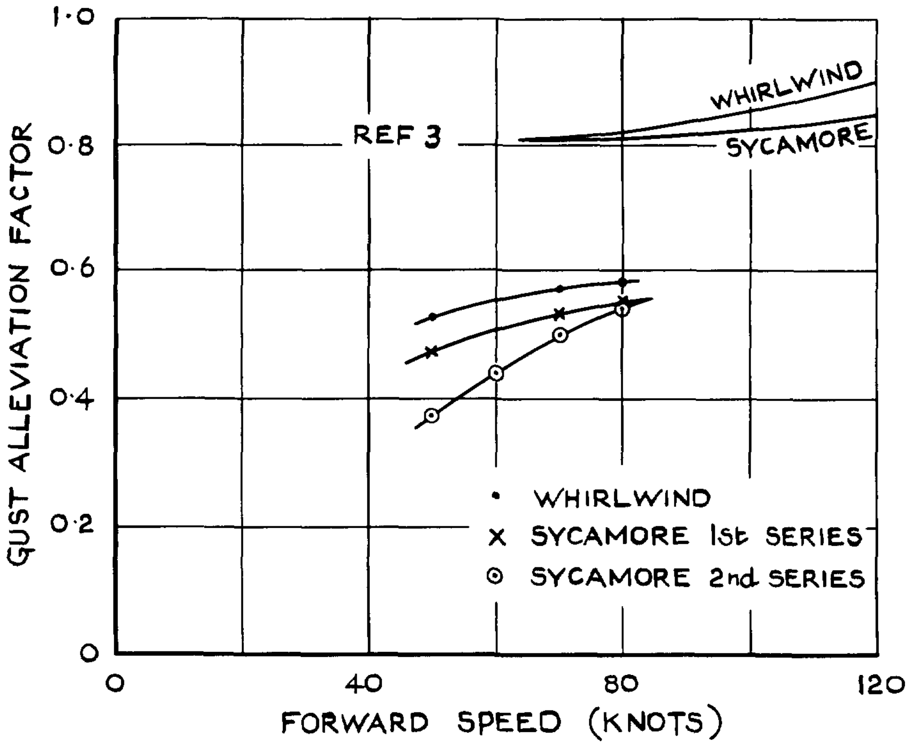

FIG. 6 GUST ALLEVIATION FACTOR v FORWARD SPEED

Printed in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough. Dd.125875. K5.

A.R.C. C.P. No.878

533.6.048.5 :
531.113 :
533.661 :
533.65 :
551.511.6 :

Webber, D.A.

COMPARISON OF HELICOPTER AND AEROPLANE VERTICAL ACCELERATIONS IN TURBULENCE

August 1965

Counts of acceleration increments were recorded in a helicopter and an aeroplane flying through the same weather. The accelerations were compared and values for the gust alleviation factor for the helicopter were deduced. It is shown that these values increase with forward speed and at the highest forward speed attained are in reasonable agreement with the American MIL-S-8698 requirements.

A.R.C. C.P. No.878

533.6.048.5 :
531.113 :
533.661 :
533.65 :
551.511.6 :

Webber, D.A.

COMPARISON OF HELICOPTER AND AEROPLANE VERICAL ACCELERATIONS IN TURBULENCE

August 1965

Counts of acceleration increments were recorded in a helicopter and an aeroplane flying through the same weather. The accelerations were compared and values for the gust alleviation factor for the helicopter were deduced. It is shown that these values increase with forward speed and at the highest forward speed attained are in reasonable agreement with the American MIL-S-8698 requirements.

A.R.C. C.P. No.878

533.6.048.5 :
531.113 :
533.661 :
533.65 :
551.511.6 :

Webber, D.A.

COMPARISON OF HELICOPTER AND AEROPLANE VERTICAL ACCELERATIONS IN TURBULENCE

August 1965

Counts of acceleration increments were recorded in a helicopter and an aeroplane flying through the same weather. The accelerations tere compared and values for the gust alleviation factor for the helicopter were deduced. It is shown that these values increase with forward speed and at the highest forward speed attained are in reasonable agreement with the American MIL-S-8698 requirements.

DETACHABLE ABSTRACT CARDS

C.P. No. 878

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
49 High Holborn, London W.C.1
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
Brazennose Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

C.P. No. 878

S.O. CODE No. 23-9016-78