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Loads Experienced in Turbulence by a Central African Airways Viscount Without and With Cloud Warning Radar

by

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LOADS EXPERIENCED IN TURBULENCE BY A CENTRAL AFRICAN AIRWAYS VISCOUNT WITHOUT AND WITH CLOUD WARNING RADAR

by

N.I. Bullen
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SUMMARY

Counting accelerometer records were obtained from a Central African Airways Viscount. After a year's recording, cloud warning radar was fitted to the aircraft and data for a further three years were obtained. A comparison is made between the loads experienced during the two periods and it is concluded that the carrying of radar has little effect on fatigue damage, but considerably reduces the frequency of high loads, at 1 g the reduction being by a factor of six.

* Replaces R.A.E. Technical Report 68065 - A.R.C. 30708.

CONTENTS

1 INTRODUCTION

As part of the programme for recording aircraft accelerations in flight, a counting accelerometer was carried on a Viscount type 748 of the Central African Airways Corporation. During the period covered by the observations, cloud warning radar was fitted, so that it is possible to make a direct assessment of the value of this aid. The period covered without radar was approximately one year, from September 1956 to August 1957, and the period with radar from September 1957 to September 1960. The periods of useful recording were, without radar, 358 hours and with radar, 1322 hours.

The present work is considered to carry more weight than earlier comparisons of this nature. A comparison with Comet aircraft[1] involved different operators, B.O.A.C. and R.A.F. Transport Command, and it is likely that operational factors contributed to the observed differences. An American paper[2] makes the comparison using both V-g-h and V-g data, but as the period without radar extended only from October 1955 to April 1956 while the period with radar covered a whole year, seasonal variations are likely to affect the results.

However, the indications were that the large loads were considerably reduced (about 25% in magnitude), but that there was no significant change in the frequency of the small loads. There was no apparent effect upon the airspeed practices.

The present analysis suffers from neither of these drawbacks, the data being acquired from the same operator, flying with the same route structure, for periods of one year and three years, respectively.

2 THE COUNTING ACCELEROMETER

The counting accelerometer is an instrument designed specifically for operational recording[3,4]. Basically, it is an accelerometer which actuates a series of counters at preset acceleration levels. On exceeding a given increment of acceleration, the counter is cocked, and the count is completed when the acceleration returns to a second preset lower level. For the Mk.IV instrument used in the present investigation, these values are given in the table below.

Acceleration increments required
to record an occurrence

Counter cocked	Count Completed
0.2 g	0.0 g
0.3 g	0.0 g
0.4 g	0.1 g
0.6 g	0.2 g
0.8 g	0.3 g
1.0 g	0.4 g
1.2 g	0.6 g
1.4 g	0.8 g
1.6 g	1.0 g

A further property of the accelerometer which is worth bearing in mind is that it has two degrees of freedom, so that by a careful choice of parameters, its response is more at the disposal of the experimenter than is the case with an instrument having a single degree of freedom.

In the present instrument the response is fairly flat up to 10 Hz and then falls away rapidly, inversely as the fourth power of the frequency. The response is shown diagrammatically in Fig.1.

The accelerometer is mounted rigidly near the centre of gravity of the aircraft and the counter readings are photographically recorded at time intervals of approximately 10 minutes, together with the time and the height and speed of the aircraft. The information from the film is subsequently transferred to punched cards for analysis.

3 DETERMINATION OF EQUIVALENT GUST VELOCITIES

When comparisons between the turbulence encountered by different types of aircraft are required, it is convenient to convert the accelerations to equivalent gust velocities. This procedure, described by Zbrozek[5], assumes an arbitrary gust shape, and that the aircraft is rigid and does not pitch, account being taken of the unsteady lift for a finite aspect ratio wing. The gust profile assumed is ramp-shaped with a gradient distance of 100 ft. The computer programme employed in the analysis is described by Heath-Smith[6].

For the purpose of the present comparison, in examining the effect of the radar on aircraft loads and the discomfort of the occupants, it is preferable to consider the accelerations themselves. In a comparison of the turbulence actually encountered by the aircraft in the two cases, the derived gust velocities are the more appropriate. A convenient empirical formula for aircraft response is derived in the Appendix.

4 BASIC DATA

The routes flown by the aircraft are shown in Fig.2, and their frequencies for the periods without and with radar are given in Table 1. It will be seen that there is no appreciable difference in route structure for the two periods.

The recorded accelerations and derived gust velocities for the two periods are presented in Tables 2-5 in the standard format used for these investigations. The category "initial climb" comprises information from the first intervals after take-off, and "final descent" comprises information from the final interval before landing. "Climb" and "descent" are intervals during which the altitude, rounded to the nearest 1000 ft, has changed by more than 1000 ft in the appropriate direction; "cruise" comprises the remainder.

For the purposes of the present comparison the classification in Tables 3-6 spreads out the data rather too thinly, and it has been decided to reduce the classes to four, namely:

(i) all flying below 3500 ft,
(ii) all flying from 3500 to 9500 ft,
(iii) climb and descent above 9500 ft, and,
(iv) cruise above 9500 ft.

Furthermore, the up gusts and down gusts have been added. The result of this is given in Table 6 which also includes the frequencies per mile of flight and the mean speeds in knots eas.

5 DISCUSSION OF RESULTS

The information is presented diagrammatically in Figs.3-6, Figs.3 and 4 being based on the accelerations and 5 and 6 on equivalent gust velocities (only points based on five or more occurrences are shown).

It will be seen that for the lower accelerations of about 0.2 g, the frequencies with and without radar are almost identical. What difference there are in the flying below 9500 ft for accelerations of about 0.4 g show small increases when carrying radar. Larger loads are only encountered with significant frequency above 9500 ft and here the benefit from the radar becomes considerable, particularly in the cruise.

The diagrams for equivalent gust velocities, as might be expected, show much the same trends. However, at the low gust velocity of 10 ft/sec there is a slight reduction with radar in the frequency of encounter. This reduction is almost entirely counteracted by the small increases in speed shown in Table 7, so that the accelerations of 0.2 g, as already seen, are practically unchanged.

The increase in speed is probably due to the increased confidence given by the use of radar (the small change in average height is due to a reduction in permitted differential cabin pressure).

The reduction of speed when in turbulence may be examined in the following way. By taking points corresponding to equal frequencies on the acceleration and gust velocity curves, we can find the acceleration corresponding to a given gust velocity. If we now assume an average height and weight for the given flight condition, we can determine the corresponding speed from the expression for aircraft response derived in the Appendix.

The fact that an average height and weight are assumed does, of course, introduce an experimental scatter so that the method is not particularly reliable at the highest gust velocities. However, the method has been applied at 10 ft/sec and 20 ft/sec with the results shown in the following table.

Flight condition		Mean speed knots eas	Speed of encountering gusts of 10 ft/sec or more knots eas	Speed of encountering gusts of 20 ft/sec or more knots eas
Without radar	All flying below 3500 ft	150	146	141
	All flying from 3500 ft to 9500 ft	150	143	140
	Climb and descent above 9500 ft	160	154	157
	Cruise above 9500 ft	182	171	181
With radar	All flying below 3500 ft	159	154	152
	All flying from 3500 ft to 9500 ft	159	155	152
	Climb and descent above 9500 ft	173	165	171
	Cruise above 9500 ft	194	182	175

Without radar there is a reduction in the speed of encountering 10 ft/sec gusts or greater, of from 4-11 knots; and below 9500 ft the reduction is much the same for 20 ft/sec gusts or greater.

Above 9500 ft and particularly during cruise, the speed of encounter for 20 ft/sec gusts or greater is not significantly lower than the mean speeds. This implies that the majority of the larger loads are unexpected and therefore probably not associated with the lower intensity turbulence for which a reduction in speed is observed.

With radar the general picture is much the same with one rather striking exception. In cruise for the 20 ft/sec gusts and greater, a reduction in speed of 19 knots is indicated compared with 1 knot without radar, and this presumably is an indication of adequate warning.

It is rather surprising that the speeds for climb and descent above 9500 ft do not show the same trend but remain very similar to the differences observed without radar.

These inferences are of a tentative nature as the averaging process may have introduced appreciable errors. However, it seems that reductions of speed in turbulence are facilitated by the use of radar, although not necessarily taking place in all cases. This conclusion would be in agreement with the findings of King[7]. After examining over 3000 hours of a V-g-h recording on current passenger transports carrying radar, he concludes:-

"Nine of the 24 patches of turbulence examined occurred without warning as to their severity. Thus, although the technique of reducing airspeed in turbulence benefits fatigue life and passenger comfort, it cannot ensure that the largest gusts are always met at the reduced airspeed."

6 ACCELERATION FREQUENCY DISTRIBUTIONS

In the majority of studies of gust loads on aircraft, it is found that their frequency distributions can be well represented by the sum of two exponential terms, one representing a light turbulence component and the other a severe turbulence component, usually identified with cumulus or storm disturbance. Such distributions have been fitted to the accelerations* recorded in both flight conditions over 9500 ft, the expression being:-

$$N = A_1 e^{-n/a_1} + A_2 e^{-n/a_2} \qquad (1)$$

where N is the number of accelerations per mile of flight exceeding ng and A_1 and A_2, a_1 and a_2 are constants. A_1 and A_2 have dimensions "number per mile" and a_1 and a_2 are accelerations in g units.

The values of A_1 and A_2 can be taken as measures of the times spent in turbulence of each intensity and a_1 and a_2 as measures of the intensity. Since the acceleration data contain only significant numbers of counts at the first four levels and expression (1) contains four parameters, the expression is fitted over this range exactly. Little or no information remains for testing "goodness of fit".

The values of the parameters so determined are given in the following comparison table.

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* Accelerations rather than gust velocities are chosen for this fitting as the gust frequencies are already an interpolation from the data, and as the lowest value of gust velocity, 10 ft/sec, for which a frequency is given corresponds almost always to an acceleration above 0.2 g, the information would not be used to the full. It also seems possible that a slight bias has been introduced by the method of analysing the "tails" of the distribution as the experimental points of Figs.5 and 6 at the higher gust velocities show small deviations from the smooth curve.

		Without radar	With radar
Mean take-off weight, lb		54410	54980
Mean landing weight, lb		49470	50540
Mean weight, lb		51940	52760
Climb and descent above 9500 ft	Mean height, ft	14320	13560
	Mean speed knots, eas	160.0	173.1
	A_1 per mile	0.1127	0.0870
	A_2 per mile	2.014	2.870
	a_1 "g" units	0.1089	0.1018
	a_2 "g" units	0.04319	0.04225
Cruise above 9500 ft	Mean height, ft	17650	16540
	Mean speed knots, eas	182.0	193.7
	A_1 per mile	0.02811	0.02638
	A_2 per mile	0.4154	0.8216
	a_1 "g" units	0.1370	0.1109
	a_2 "g" units	0.04685	0.04336

During cruise the time spent in severe turbulence is very slightly reduced when carrying radar (about 6%), but the time spent in light turbulence is doubled. The intensity of the loads in severe turbulence however, is very much reduced, about 19%, although the reduction in intensity when in light turbulence is much smaller, about 7%.

Similar but generally smaller trends are observed in climb and descent above 9500 ft. With radar the time spent in severe turbulence is about 25% less, for the light turbulence 40% more; the intensity in severe turbulence 7% less, and in light turbulence 2% less.

These results again show that the use of radar increases the time spent in turbulence of a light nature but leads to a general reduction in the intensity of turbulence encountered which becomes particularly marked for the most severe turbulence.

Extrapolating the distributions, assuming it to be justified, we find that the frequency of loads at 1 g during cruise, is six times as frequent without radar.

7 CONCLUSIONS

The use of cloud warning radar leads to an increased confidence resulting in slightly higher operating speeds and some increase in the amount of light turbulence encountered. Heavy turbulence is slightly reduced in amount and considerably reduced in intensity. For the most damaging fatigue loads, the frequencies are practically unchanged so that there is little effect on fatigue life but there is considerable reduction in the frequency of high loads.

During cruise, if the aircraft carries radar, passengers are just as likely to spill their coffee, but only one-sixth as likely to hit the cabin roof if not wearing seat belts.

Acknowledgement

We are pleased to have this opportunity to acknowledge with thanks the kind cooperation of Central African Airways Corporation in collecting the data and for their helpful comments.

Appendix

A convenient empirical formula for aircraft response to the ramp-shaped gust can be derived as follows. We have

$$nW = \tfrac{1}{2} \rho_o S U_e V_e a K \tag{A-1}$$

where n is the aircraft normal acceleration in g

W is the aircraft weight in lb

ρ_o is air density at sea level, slugs/ft^3

S is the wing area, ft^2

U_e is the gust velocity eas, ft/sec

V_e is the aircraft forward speed, eas ft/sec

a is the slope of the lift curve per radian

K is the gust alleviation factor and is a function of aspect ratio and mass parameter μ_g. The mass parameter is given by

$$\mu_g = \frac{2W}{\rho\ Scag} \tag{A-2}$$

where the quantities not already defined are

ρ the air density, slugs/ft^3

c the mean chord, ft

g acceleration of gravity, ft/sec^2.

For a given aircraft, over the range of μ_g at which it operates, it is usually found that the relationship between $\frac{1}{K}$ and $\frac{1}{\mu_g}$ is approximately linear, so that K may be written as

$$K = \frac{p\ \mu_g}{\mu_g + q} \tag{A-3}$$

where p and q are constants.

Substituting the expression given by (A-2) for μ_g in (A-3), and substituting the resulting expression for K in (A-1) and re-arranging gives finally

$$U_e V_e = n \left(\frac{2W}{p\rho_o Sa} + \frac{q\sigma\ cg}{p} \right) \tag{A-4}$$

where σ is the relative density, ρ/ρ_o.

For the Viscount discussed in the main text $S = 963\ \mathrm{ft}^2$, $c = 10.24$ ft, $a = 4.6$ per radian. It is found that

$$K = \frac{0.969\,\mu_g}{\mu_g + 6.7} \qquad \text{(A-5)}$$

and

$$U_e\,V_e = n\,(0.1959\,W + 2280\,\sigma)\ . \qquad \text{(A-6)}$$

Such an empirical formula is very useful when considering the effects of small changes in height, weight or speed, when interpolation between several sets of curves is likely to introduce errors of the same order as the differences under examination.

Table 1

ROUTES FLOWN

Route (or return)		Miles	Number without radar	Number with radar	Total number
Benina	Khartoum	1385	2	-	2
Benina	Wadi Halfa	983	4	14	18
Blantyre	Dar-es-Salaam	684	2	13	15
Blantyre	Lusaka	458	1		1
Blantyre	Salisbury	320	3	64	67
Bulawayo	Johannesburg	407		21	21
Bulawayo	Lusaka	305	1		1
Bulawayo	Salisbury	224	1	87	88
Dar-es-Salaam	Nairobi	410	2	14	16
Durban	Lourenço-Marques	288	5	14	19
Durban	Salisbury	780	2	22	24
Elisabethville	N'Dola	124	2	10	12
Entebbe	Khartoum	1058	6	13	19
Entebbe	N'Dola	930	5	13	18
Entebbe	Salisbury	1232	1		1
Johannesburg	Livingstone	576	4	13	17
Johannesburg	Salisbury	599	22	75	97
Kariba	Lusaka	71		1	1
Kariba	Salisbury	170		3	3
Khartoum	Wadi Halfa	455	4	13	17
Livingstone	Lusaka	232	4	9	13
Livingstone	N'Dola	385		8	8
Livingstone	Salisbury	356		5	5
Lourenço-Marques	Salisbury	520	5	11	16
Lusaka	N'Dola	184	58	144	202
Lusaka	Salisbury	232	52	134	186
Nairobi	N'Dola	995	6	44	50
Nairobi	Salisbury	1219		1	1
N'Dola	Salisbury	368	12	37	49
Benina	Rome	800	6	16	22
London	Marseilles	629	1		1
London	Rome	890	5	18	23
Marseilles	Rome	367	1		1
	TOTALS		217	817	1034

Mean route length without radar 417 miles

Mean route length with radar 418 miles

Table 2

CAAC VISCOUNT (WITHOUT CLOUD WARNING RADAR) ACCELERATIONS RECORDED

Flight Condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each acceleration increment was exceeded										
					DOWN					UP					
					0.8 g	0.6 g	0.4 g	0.3 g	0.2 g	0.2 g	0.3 g	0.4 g	0.6 g	0.8 g	1.0 g
Initial climb	0 - 1500	1000	34	103				2	26	52	9	1			
	1500 - 3500	2800	493	1501			3	26	274	391	38	4			
	3500 - 5500	4000	226	691		1	3	10	132	198	20	1			
TOTAL			753	2295		1	6	38	432	641	67	6			
Final descent	0 - 1500	700	51	140				4	52	67	9	1			
	1500 - 3500	2500	26	71					19	21					
	3500 - 5500	4600	232	658			1	11	211	253	44	5			
	5500 - 9500	6300	48	150			1	3	48	52	9				
TOTAL			357	1019			2	18	330	393	62	6			
Climb and descent	0 - 1500	1000	14	37				4	20	17	2				
	1500 - 3500	2600	83	242					28	38	4				
	3500 - 5500	4700	212	632				7	73	86	12	1			
	5500 - 9500	7800	1648	5300			9	58	395	435	55	8			
	9500 - 13500	11900	2189	7953		1	9	35	167	151	33	9	2		
	13500 - 17500	15200	2384	9354		1	14	38	155	144	41	12	2		
	17500 - 21500	18700	522	2172		2	8	18	56	66	14	8	1	1	1
	21500 - 25500	22600	43	182											
TOTAL			7095	25872		4	40	160	894	937	161	38	5	1	1
Cruise	0 - 1500	800	13	35				5	38	61	11	1			
	1500 - 3500	2200	17	46					14	18	12				
	3500 - 5500	4700	96	276				4	45	52	10	1			
	5500 - 9500	7200	207	790			2	6	47	58	12	2			
	9500 - 13500	12000	658	2791		1	5	24	58	52	18	10	1		
	13500 - 17500	16000	4971	22571			4	18	107	124	36	14	3	2	
	17500 - 21500	18800	6623	30741	2	7	25	63	187	195	67	37	9	1	
	21500 - 25500	22800	672	3315				1	5	6	1				
	25500 - 29500	26000	11	58											
TOTAL			13268	60623	2	8	36	121	501	566	167	65	13	3	

Table 3

CAAC VISCOUNT (WITHOUT CLOUD WARNING RADAR) GUSTS ENCOUNTERED

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec eas													
					DOWN						UP							
					35	30	25	20	15	10	10	15	20	25	30	35	40	45
Initial climb	0 - 1500	1000	34	103					4	30	83	12	2	1				
	1500 - 3500	2800	493	1501				3	22	236	342	33	4	1				
	3500 - 5500	4000	226	691		1	2	3	9	126	187	18	1					
TOTAL			753	2295		1	2	6	35	392	612	63	7	2				
Final descent	0 - 1500	700	51	140					4	70	84	12	2					
	1500 - 3500	2500	26	71					1	24	22							
	3500 - 5500	4600	232	658				1	19	261	289	45	10	2				
	5500 - 9500	6300	48	150					2	36	42	5						
TOTAL			357	1019				1	26	391	437	62	12	2				
Climb and descent	0 - 1500	1000	14	37					5	24	19	3						
	1500 - 3500	2600	83	242						24	33	4						
	3500 - 5500	4700	212	632					8	87	105	13	1					
	5500 - 9500	7800	1648	5300			1	7	51	371	393	50	8	2				
	9500 - 13500	11900	2189	7953		1	3	7	27	123	109	23	7	4	2			
	13500 - 17500	15200	2384	9354			4	9	26	118	104	26	5	1	1			
	17500 - 21500	18700	522	2172			1	4	10	29	26	9	3	1	1	1	1	
	21500 - 25500	22600	43	182														
TOTAL			7095	25872		1	9	27	127	776	789	128	24	8	4	1	1	
Cruise	0 - 1500	800	13	35					7	46	73	14	2					
	1500 - 3500	2200	17	46						16	18	12	1					
	3500 - 5500	4700	96	276				1	8	54	66	13	3	1				
	5500 - 9500	7200	207	790				1	5	40	50	9	3	1				
	9500 - 13500	12000	658	2791			1	2	9	39	35	11	3	1				
	13500 - 17500	16000	4971	22571					5	37	61	17	5	2	2			
	17500 - 21500	18800	6623	30741	1	2	4	10	26	96	100	37	14	5	1	1		
	21500 - 25500	22800	672	3315						3	3							
	25500 - 29500	26000	11	58														
TOTAL			13268	60623	1	2	5	14	60	331	406	113	31	10	3	1		

Table 4

CAAC VISCOUNT (WITH CLOUD WARNING RADAR) ACCELERATIONS RECORDED

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each acceleration increment was exceeded										
					DOWN					UP					
					0.8 g	0.6 g	0.4 g	0.3 g	0.2 g	0.2 g	0.3 g	0.4 g	0.6 g	0.8 g	1.0 g
Initial climb	0 - 1500	1000	87	287				3	38	52	7				
	1500 - 3500	2800	1567	5100		1	32	202	1476	1852	278	36	2		
	3500 - 5500	4000	1054	3553			9	96	809	808	111	8			
	5500 - 9500	7000	14	48				1	5	6					
TOTAL			2722	8988		1	41	302	2328	2718	396	44	2		
Final descent	0 - 1500	700	131	369				5	55	67	13				
	1500 - 3500	2600	165	489			2	13	97	159	23	3			
	3500 - 5500	4700	824	2488			7	52	384	466	65	15			
	5500 - 9500	6200	378	1209			3	34	261	300	32	2			
TOTAL			1498	4555			12	104	797	992	133	20			
Climb and descent	0 - 1500	1000	36	104					5	12					
	1500 - 3500	2500	234	705			1	10	50	73	6	3	1	1	
	3500 - 5500	4700	777	2504			2	28	222	299	37	8			
	5500 - 9500	7900	6005	20711		2	47	292	2063	2017	318	44			
	9500 - 13500	12000	10430	41631	1	8	41	161	890	763	118	27	6	1	
	13500 - 17500	15000	6857	28618			32	95	480	471	100	29	3		
	17500 - 21500	18700	899	4069			5	24	90	94	19	10	1		
	21500 - 25500	23500	54	258					3	1					
TOTAL			25292	98600	1	10	128	610	3803	3730	598	121	11	2	
Cruise	0 - 1500	900	35	101					4	8					
	1500 - 3500	2800	51	159					0	1					
	3500 - 5500	4700	253	790			8	53	261	325	70	11			
	5500 - 9500	7600	311	1164			5	29	161	201	32	6			
	9500 - 13500	11900	1102	4832	1	2	9	27	147	127	33	13	3		
	13500 - 17500	15700	33725	162159	2	7	54	189	966	846	184	49	6	2	
	17500 - 21500	18700	13867	67091		2	31	93	432	415	81	32	8	1	
	21500 - 25500	22600	412	1895					6	7					
	25500 - 29500	26000	35	164					4	1	1				
TOTAL			49791	238355	3	11	107	391	1981	1931	501	111	17	3	

Table 5

CAAC VISCOUNT (WITH CLOUD WARNING RADAR) GUSTS ENCOUNTERED

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec eas.													
					DOWN						UP							
					35	30	25	20	15	10	10	15	20	25	30	35	40	45
Initial climb	0 - 1500	1000	87	287					3	36	56	7						
	1500 - 3500	2800	1567	5100			6	24	142	1141	1499	195	26	6	1			
	3500 - 5500	4000	1054	3553			1	5	55	514	549	52	3					
	5500 - 9500	7000	14	48						2	1							
TOTAL			2722	8988			7	29	200	1693	2105	254	29	6	1			
Final descent	0 - 1500	700	131	369					6	58	66	16						
	1500 - 3500	2600	165	489				2	10	89	146	19	3					
	3500 - 5500	4700	824	2488			1	5	34	297	366	49	10	1				
	5500 - 9500	6200	378	1209				3	25	205	241	18	2					
TOTAL			1498	4555			1	10	75	649	819	102	15	1				
Climb and descent	0 - 1500	1000	36	104						6	10							
	1500 - 3500	2500	234	705					7	47	59	4	2	1	1	1	1	1
	3500 - 5500	4700	777	2504			1	3	28	218	289	43	9	4				
	5500 - 9500	7900	6005	20711			8	33	181	1463	1524	197	26	3				
	9500 - 13500	12000	10430	41631		1	4	17	78	495	410	58	12	3				
	13500 - 17500	15000	6857	28618			1	9	43	228	243	38	9	2				
	17500 - 21500	18700	899	4069				2	12	43	43	14	5	1				
	21500 - 25500	23500	54	258						-	-							
TOTAL			25292	98600		1	14	64	349	2500	2578	354	63	14	1	1	1	1
Cruise	0 - 1500	900	35	101						2	4							
	1500 - 3500	2800	51	159						0	1							
	3500 - 5500	4700	253	790			1	5	38	205	270	48	9	1				
	5500 - 9500	7600	311	1164				2	12	96	122	16	1					
	9500 - 13500	11900	1102	4832		1	1	4	13	57	55	13	6	1				
	13500 - 17500	15700	33725	162159		1	6	14	47	301	295	49	13	4	1			
	17500 - 21500	18700	13867	67091			2	12	39	172	170	41	16	5	1			
	21500 - 25500	22600	412	1895						1	1							
	25500 - 29500	26000	35	164						1	1							
TOTAL			49791	238355		2	10	37	149	835	919	167	45	11	2			

Table 6

SUMMARY OF ACCELERATION AND GUST FREQUENCIES

WITHOUT CLOUD WARNING RADAR

Flight condition	Distance miles	Mean height feet	Mean speed knots eas		Acceleration increments exceeding						Gusts exceeding							
					0.2 g	0.3 g	0 4 g	0.6 g	0.8 g	1.0 g	10 ft/sec	15 ft/sec	20 ft/sec	25 ft/sec	30 ft/sec	35 ft/sec	40 ft/sec	45 ft/sec
All flying below 3500 ft	2175	2472	149.5	Number	1136	126	10				1144	133	14	2				
				No. per mile	5.223,-1	5.793,-2	4.598,-3				5.260,-1	6.115,-2	6.437,-3	9.195,-4				
All flying from 3500 ft to 9500 ft	8497	6830	149.8	Number	2085	261	34	1			2107	255	39	9	1			
				No. per mile	2.454,-1	3.072,-2	4.001,-3	1.177,-4			2.480,-1	3.001,-2	4.590,-3	1.059,-3	1.177,-4			
Climb and descent above 9500 ft	19661	14320	160.0	Number	739	179	60	9	1	1	509	121	35	14	5	1	1	
				No. per mile	3.759,-2	9.104,-3	3.052,-3	4.578,-4	5.086,-5	5.086,-5	2.589,-2	6.154,-3	1.780,-3	7.121,-4	2.543,-4	5.086,-5	5.086,-5	
Cruise above 9500 ft	59476	17648	182 0	Number	734	228	95	21	5		374	105	34	13	5	2		
				No. per mile	1.234,-2	3 833,-3	1.597,-3	3.531,-4	8.407,-5		6.288,-3	1.765,-3	5.717,-4	2.186,-4	8.407,-5	3.363,-5		

WITH CLOUD WARNING RADAR

All flying below 3500 ft	7314	2529	159.2	Number	3949	560	77	4	1		3220	409	57	13	2	1	1	1
				No. per mile	5.399,-1	7 657,-2	1.053,-2	5.469,-4	1.367,-4		4.403,-1	5.592,-2	7.793,-3	1.777,-3	2.734,-4	1.367,-4	1.367,-4	1.367,-4
All flying from 3500 ft to 9500 ft	32467	6828	158.9	Number	8584	1250	175	2			6362	796	116	21				
				No. per mile	2.644,-1	3 850,-2	5.390,-3	6.160,-5			1.960,-1	2.452,-2	3.573,-3	6 468,-4				
Climb and descent above 9500 ft	74576	13557	173.1	Number	2792	517	144	18	2		1462	243	54	11	1			
				No. per mile	3 744,-2	6 933,-3	1.931,-3	2.414,-4	2 682,-5		1 960,-2	3 258,-3	7.241,-4	1 475,-4	1.341,-5			
Cruise above 9500 ft	236141	16537	193.7	Number	2951	608	188	28	6		1054	202	65	19	4			
				No. per mile	1 250,-2	2.575,-3	7.961,-4	1.186,-4	2.541,-5		4 463,-3	8.554,-4	2 753,-4	8.046,-5	1.694,-5			

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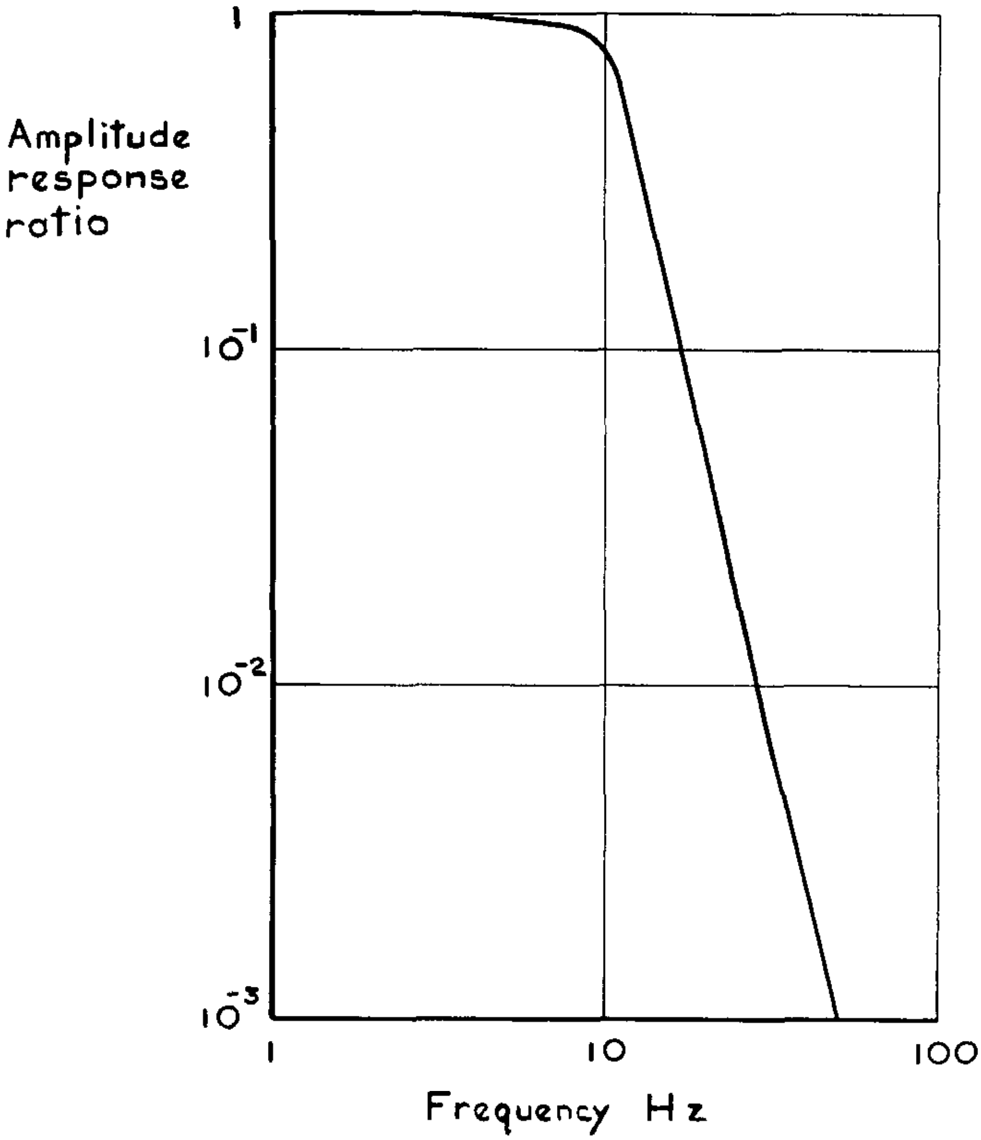

Fig.1. Accelerometer response

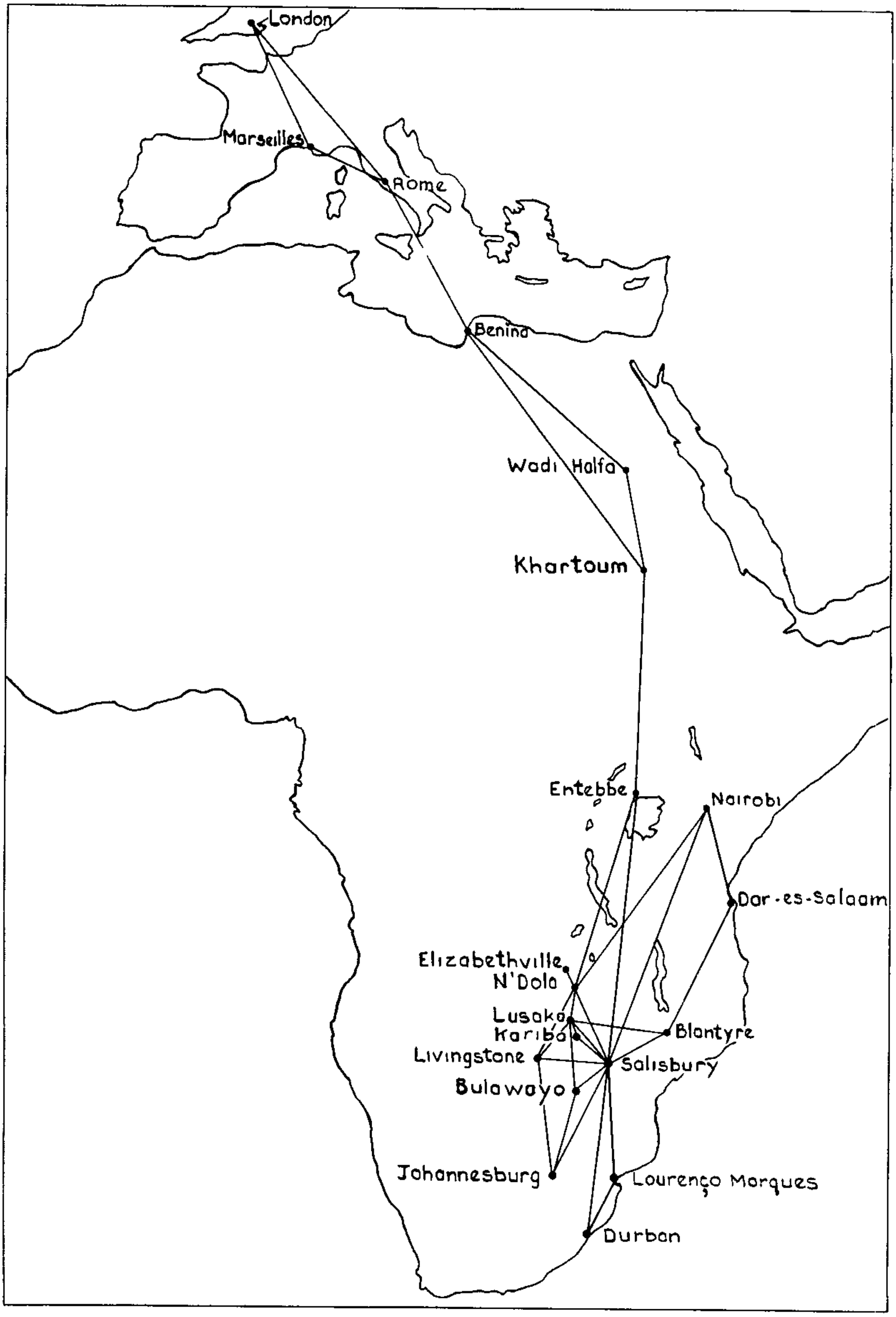

Fig 2 Routes flown

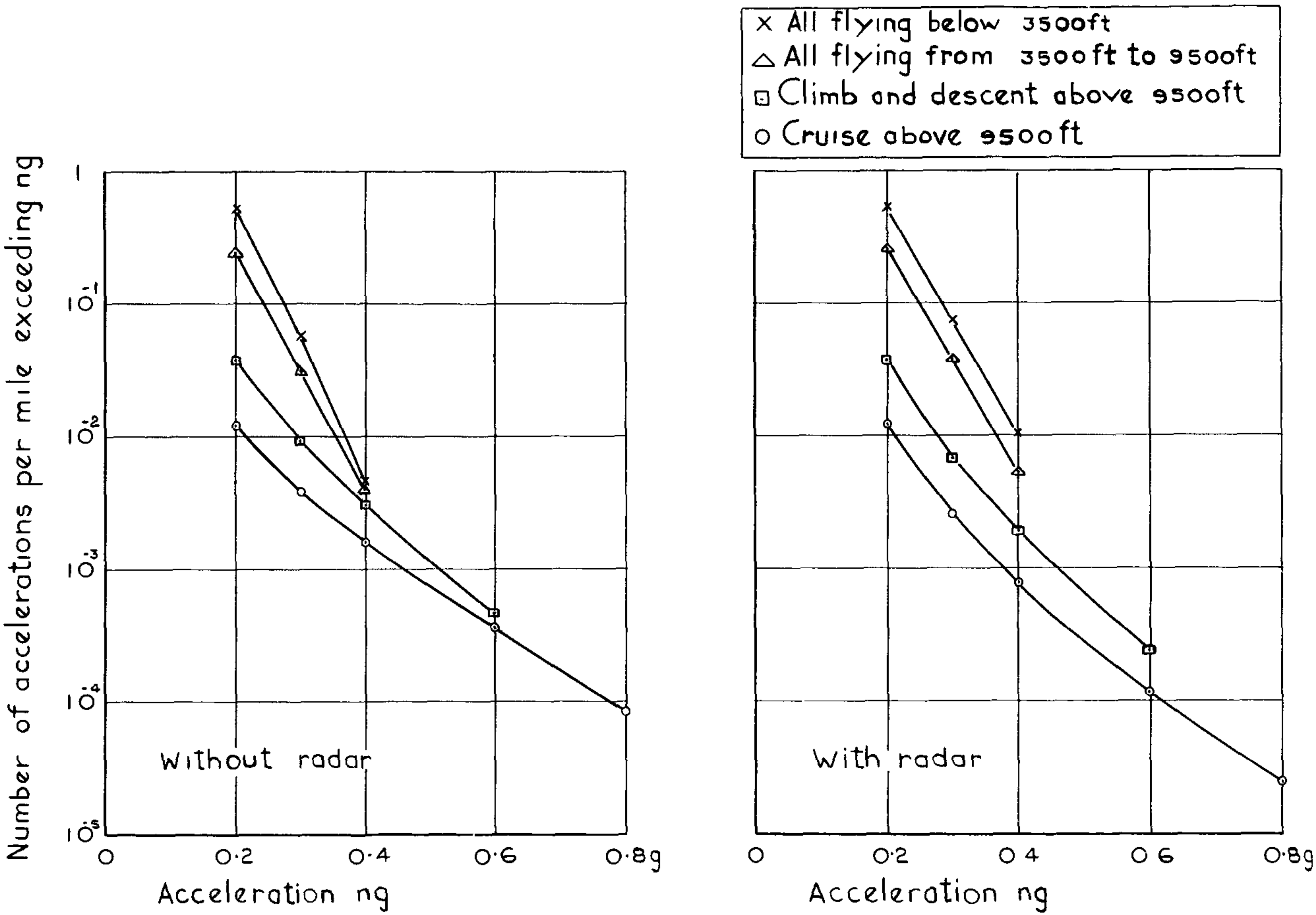

Fig.3 Accelerations experienced without and with radar

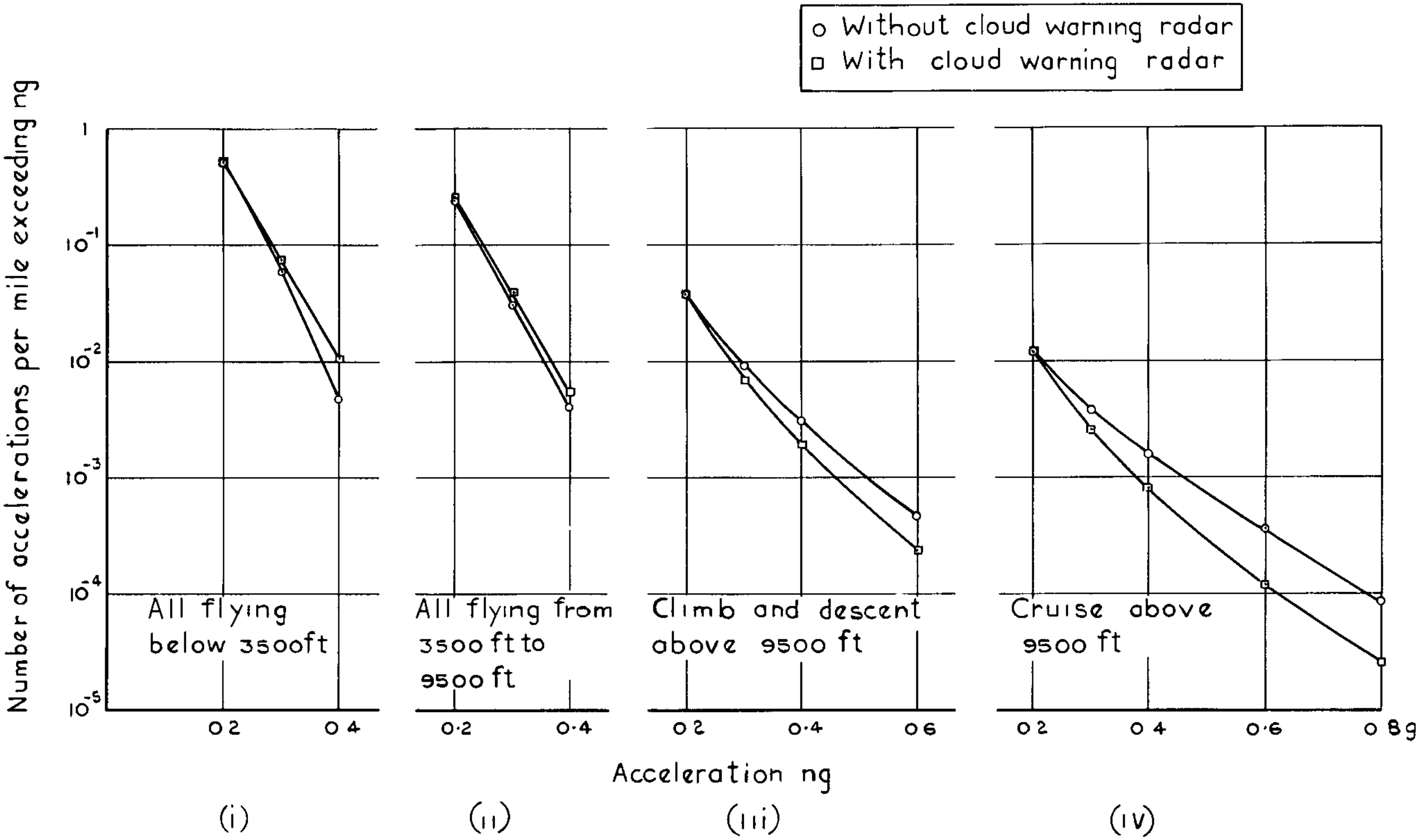

Fig 4 Comparison of accelerations experienced in each flight condition without and with radar

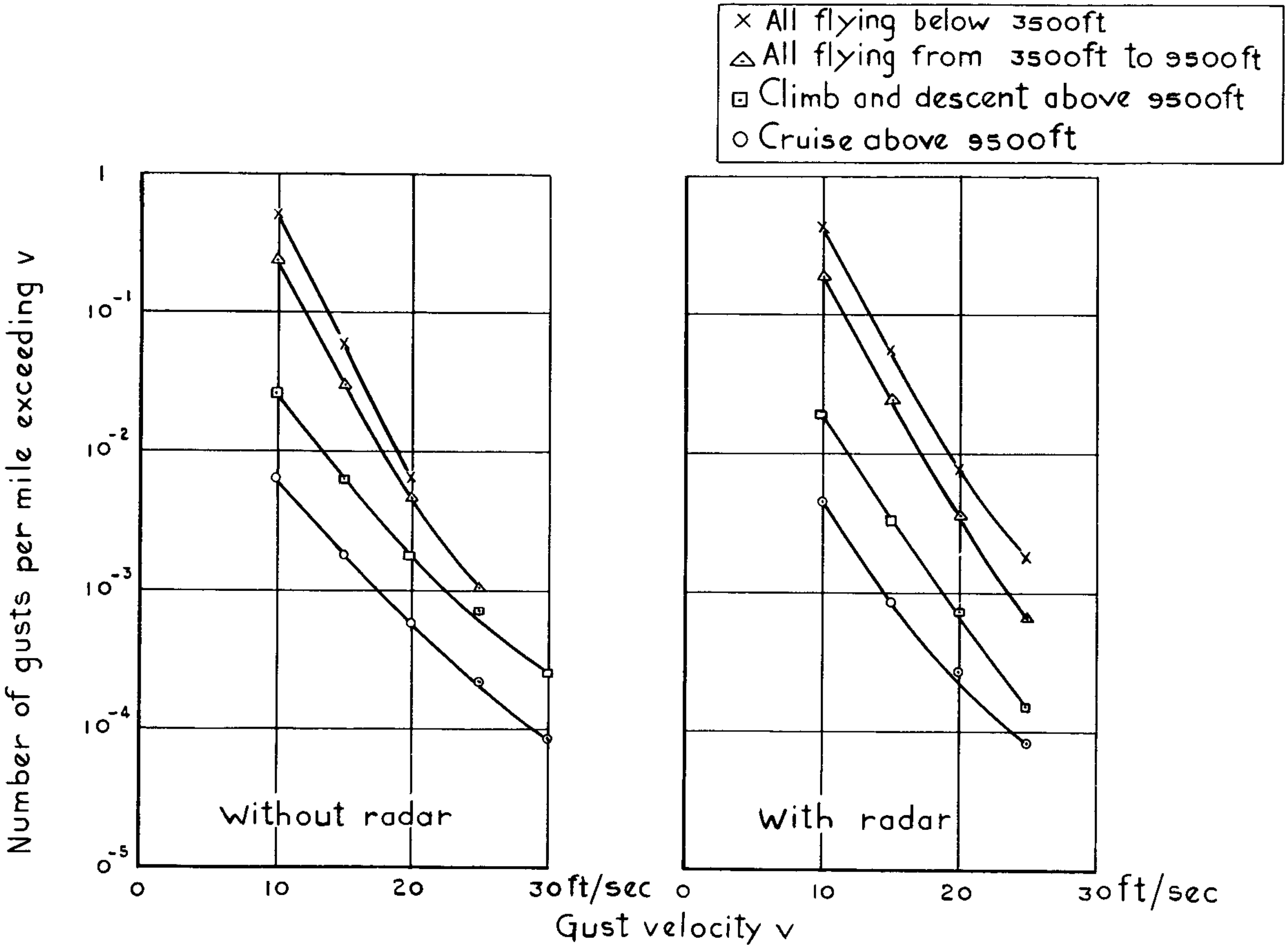

Fig 5 Equivalent gust velocities encountered without and with radar.

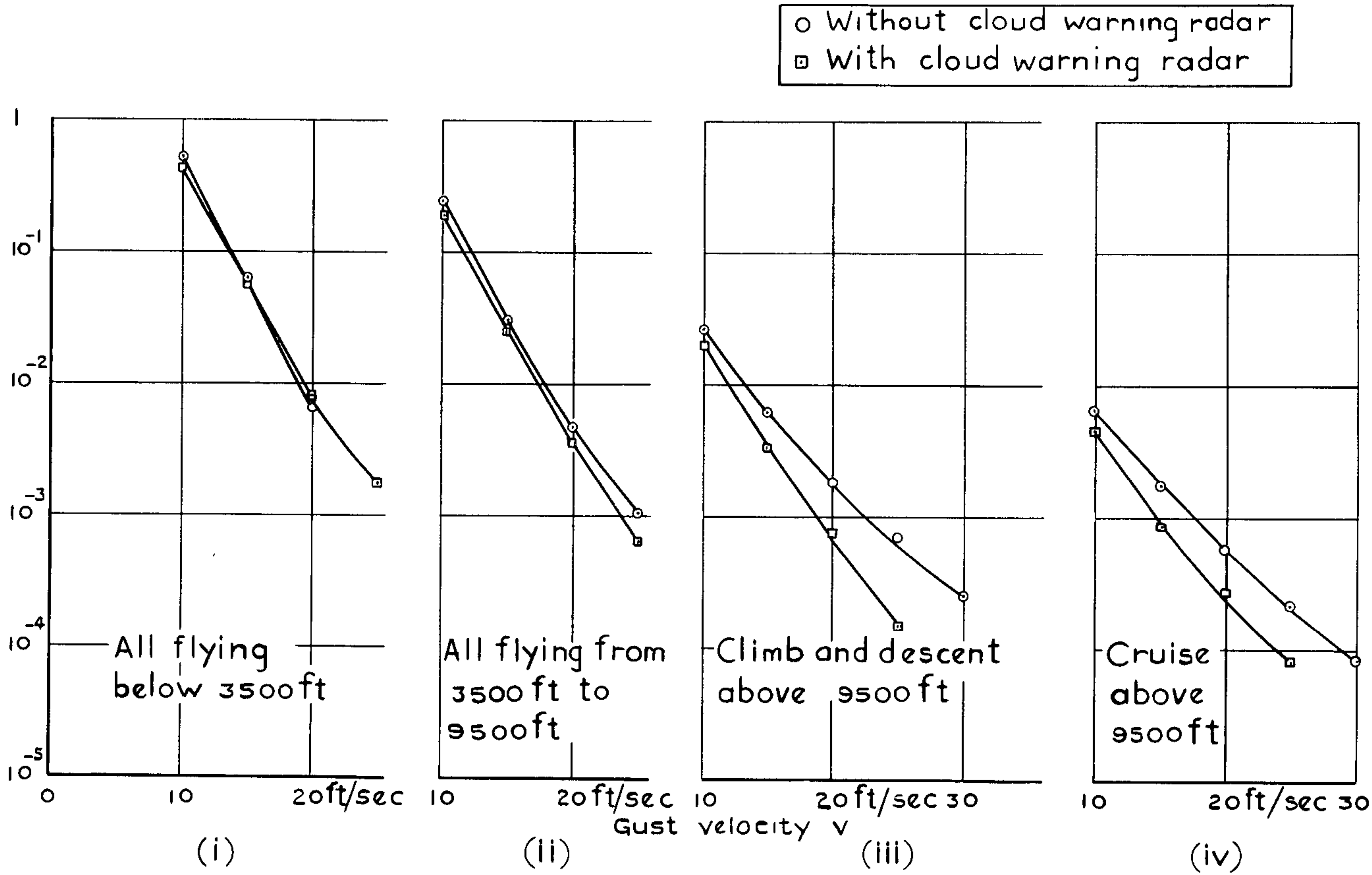

Fig.6 Comparison of equivalent gust velocities encountered in each flight condition without and with radar

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