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Gust Loads on Comet Aircraft

by

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Counting accelerometers have been used to record normal accelerations on BOAC Comet 4 and RAF Comet 4C aircraft for flight distances of 910 000 km and 388 000 km respectively. Two Comet 4 aircraft carried instruments and a significant difference is found between the frequencies of gusts observed on each. Revised data for the BOAC Comet 1 and RAF Comet 2 are presented and comparison of the four fleets shows that loads were recorded more often on the civil airline operations. The effect of the cloud warning radar carried by only the later aircraft is studied.

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1 INTRODUCTION

Centre of gravity accelerations have been recorded in passenger transport aircraft for many years and the records were extended by installing counting accelerometers on two Comet 4 and one Comet 4C aircraft operated by BOAC and RAF Transport Command respectively. In the period from November 1959 to September 1962 data were collected for 1200 flying hours of the BOAC aircraft, representing a distance of 910 000 km, and between January 1964 and February 1967, 500 flying hours (388 000 km) of the RAF aircraft were observed. In the present paper the turbulence encountered by these three aircraft is studied together with a re-analysed form of the previously published[1,2] recordings from the BOAC Comet 1 and RAF Comet 2.

2 INSTRUMENTATION

All data presented here were obtained from counting accelerometers measuring the vertical acceleration at a point near the aircraft centre of gravity. The counting accelerometer[3,4] is an instrument that counts the number of times given levels of upward or downward acceleration are exceeded, the counter for a given level being activated when the acceleration has returned to some preset lower level. The counters, a clock and instruments recording the altitude and speed of the aircraft are photographed at intervals of a few minutes. All aircraft except the Comet 1 carried the Mk.4 instrument, which incorporates an airspeed switch to ensure that recording starts after take-off and stops before landing by switching on the instrument when the airspeed exceeds 125 kn ias and switching off when it fall below 100 kn ias. The Mk.2 instrument fitted to the Comet 1 did not include this feature so that the first and last intervals of each flight included ground loads and were consequently neglected in the analysis.

3 DATA PROCESSING

The recorded data were initially coded on to punched cards. The films were read to obtain the accelerations counted at each level during each interval which were then punched on a card together with the duration in minutes of the interval and the altitude and indicated airspeed at the end of the interval. These last two quantities were recorded in units of 1000 ft and 10 kn respectively. Operational details of each flight were available on supplementary data sheets and so codes were punched representing the particular route, the date and the weight of the aircraft at take-off.

This information on cards was then processed by computer to give a modified form of these records on magnetic tape for later analysis. The airspeed and the altitude at the beginning and end of an interval were both averaged so that the acceleration counts could be associated with the mean of the flight parameters during that time. In early work these means were recorded in the same units as the original data but the accuracy of the basic data is now preserved by using units of 500 ft for the altitude and 5 kn for the airspeed. Results are subdivided by 13 altitude bands (Table 2) spaced between the mid-points of these 500 ft units. The classification of data by flight condition is according to five categories defined as follows: 'initial climb' is the first interval after take-off, 'final descent' is the last interval before landing, 'climb' and 'descent' describe other intervals, during which the altitude increased or decreased by 2000 ft or more. 'Cruise' includes all remaining observations. The initial climb and final descent records have been ignored in cases that might have included ground loads. Other information recorded on the magnetic tape included the accelerometer mark number and codes by which individual aircraft and routes may be identified.

The observations for all the Comets were written in this format and used as input for a program to calculate the required details of the flying and acceleration records, subject to specified subdivisions. The program classifies information according to flight condition and altitude band, within which it calculates the recorded time, distance, mean altitude and the number of times that each positive and negative acceleration increment was exceeded. The latter results are presented both as the measured number and the number per unit distance for each of positive, negative and combined accelerations. A similar output is produced when converting accelerations to equivalent gust velocities. In this case a gust response factor, as described later, is calculated for each interval so that the gust velocities corresponding to the levels of acceleration may be found. Thus the number of times that each of these gust velocities were exceeded is known and the following interpolation scheme is used to estimate the exceedances of a required set of velocities. If one of these falls between the equivalent velocities of two acceleration levels both of which have been exceeded once or more, a log-linear interpolation is used. If the required velocity is greater than that corresponding to the highest level exceeded then it is assumed that the number of exceedances drops to zero according to a parabola with its vertex at the next level.

Two methods of calculating the conversion from accelerations to gust velocities have been used here, both assuming that the aircraft is rigid and does not pitch. The procedure due to Zbrozek[5] assumes a discrete gust and takes account of compressibility and unsteady lift for a finite aspect ratio wing. A ramp shaped gust is used here with a basic gradient distance of 30 m; making allowance for the sweep of the Comet wing by the method of Zbrozek increases the effective gradient distance to 37 m. The other conversion to gust velocity was calculated from the gust response factor derived by the author[6]. This assumes that the atmospheric turbulence may be regarded as continuous and homogeneous in the horizontal plane with the energy of the vertical component distributed with frequency according to the Von Karman two-dimensional spectrum. The scale length used in the spectrum is equal to the inverse density ratio times 1000 ft except for flight below 1000 ft, in which case the scale length is taken to be equal to the altitude. The calculations of the response to continuous turbulence include the effects of compressibility unsteady lift, wing sweepback and spanwise variations of both the turbulence and the wing loading; the basic data is summarised in Table 1.

Throughout this paper in making conversion to gust velocity reference is made to discrete or spectral models and discrete or spectral response factors. In the particular sense used here discrete refers to the Zbrozek calculation of alleviation factor for a ramp shaped gust and spectral refers to the author's derivation of gust response factor.

It should be noted that each of these methods gives its own equivalent vertical gust velocity for a normal acceleration experienced under particular conditions. Comparisons may be made between the turbulence encountered by different aircraft using either conversion, with accuracy depending upon the compatibility of the assumptions used in the theory with the actual characteristics of the aircraft and the atmosphere. Where simple models of the turbulence and the response do not yield consistent results for different aircraft more appropriate physical models become necessary. There is little value in relating the results of the different methods but it may be noted that the equivalent gust speed given by the spectral model (Kaynes) here is about 1.5 times the equivalent gust speed given by the discrete model (Zbrozek), the variations with altitude being given in Table 3. Taylor[7] has included a constant factor of 1.2 on the response factor to allow for the

amplification by structural flexibility of the recordings of an accelerometer mounted near the centre of gravity; this constant has been omitted in this work.

Results calculated using spectral response factors have been shown both as the number per kilometre of gusts exceeding given values (equivalent to the discrete model results) and also with the number per kilometre of gusts normalised by dividing by the predicted number of zero crossings[6] for the conditions of each turbulence record. In this way allowance is made for the effect of aircraft responses on the apparent number of gusts encountered in a unit of flying distance. If applied to aircraft of differing size and geometry this gives a better comparison than would be possible using a direct acceleration to gust conversion; Taylor[7] has obtained consistent results from aircraft with a wide range of zero crossings values.

4 RESULTS OF ANALYSIS

4.1 Presentation of results

The tabulated results are classified by altitude bands which are defined in Table 2. Table 3 summarises the distance and time flown in each band by each fleet with the corresponding spatial mean values of altitude, speed, mass parameter and the gust speeds predicted by the discrete and spectral models to produce a 1 g acceleration at the aircraft centre of gravity. The ratio of the gust speeds calculated by Kaynes response factors to those of Zbrozek increases slightly with altitude, varying for the Comet 4 and 4C from 1.45 at low altitude to 1.52 under normal cruising conditions, the corresponding ratios for the earlier types of aircraft are slightly higher, namely 1.57 to 1.67 for the Comet 1 and 1.54 to 1.69 for the Comet 2. It can be seen from Table 3 and Fig.1 that the Comet 2 cruise was largely within altitude band 12 (37750 to 41750 ft) while for the other three fleets it was almost equally divided between bands 10 and 11, that is about 6000 ft lower.

The recorded accelerations for each fleet are presented in Tables 5-8, the recorded gusts as derived by the discrete model in Tables 9-12 and those for the spectral model in Tables 13-16. The basic details of the distance and time flown are repeated in each case so that complete comparisons may be made easily between aircraft within any group of tables. For most flying, except that at low level, the minimum gust speed of 2.5 m/s given in the discrete gust tables corresponds to an interpolation between the numbers of accelerations counted at the lowest two levels. So that this also applies to the tables of spectral equivalent gusts, a minimum speed of

3 m/s was chosen for these tables. The numbers of gusts have been rounded to the nearest integer, with the result that in some cases the total for all altitudes is not precisely the sum of the individual integers.

4.2 Gust frequencies for each fleet

The variation of gust frequency with gust speed for each Comet fleet at all altitudes is illustrated in Figs.2 and 4 for climb and descent, and in Figs.3 and 5 for cruise. The Comet 1, which was the only type not fitted with cloud collision warning radar, is seen to have encountered most gust speeds more frequently and also gusts of greater magnitudes than the other aircraft. During climb and descent the civil aircraft have recorded gusts appreciably more frequently than the military aircraft, which might have been caused by differences in operating techniques. The data recorded on the BOAC aircraft have approximately 65% of the total distance flown within the cruise category, as defined here, while the data for RAF operations show 75% cruise. The histograms in Fig.1 show the distribution with altitude of the total flying distance, plotted on a logarithmic scale of percentage of the total distance at all altitudes. It is noticeable that the military aircraft spent proportionally less time at the more turbulent lower altitudes. In view of this a more useful indication of gust frequency is given by subdivisions of the data such as given in Figs.6 and 7 which show the gust frequency distribution for climb and descent in altitude bands 4 to 6 and 7 to 9, and Fig.8 which applies to cruise in band 10 and above. These figures represent about 20% and 35% of the total climb and descent and 98% of the cruise respectively. Finer subdivisions would have further reduced the significance of the climb and descent samples and have introduced the effects of operational differences on the cruise. The numbers of up and down gusts have a similar distribution and so have been added together for these figures.

Fig.9 shows a modified use of the spectral response factors. Instead of the direct conversion of accelerations to gusts that is used in the discrete gust method, the number of gusts counted in each interval have been normalised by dividing by the number of zero crossings per kilometre calculated using the procedure of Ref.6. The zero crossings factor is of a similar magnitude for each Comet type and thus these gust frequency curves are nearly equivalent to the previous spectral ones (Figs.7 and 8) with a change of vertical scale.

4.3 The influence of cloud collision warning radar

The difference between the Comet 1 and the other types during high altitude cruise is marked. In the original analysis[1] of the Comet 1 data it was shown that BOAC crew weather reports associated cumulus cloud with most of the turbulence that had gusts greater than 3 m/s EAS and with all the gusts that exceeded 6 m/s EAS. The other aircraft show a reduction in the frequency of the large gusts, suggesting that the radar had been successfully used to avoid most of the severe turbulence associated with the cumulus clouds. This had previously been noted for the Comet 2[2]. By removing the accelerations recorded on the Comet 1 in known cumulus conditions the distributions of gust frequency shown by the broken lines in Fig.8 were obtained. For gust speeds greater than 3 m/s EAS (discrete gust method) these are between the gust frequency curves for the other radar equipped Comet fleets. This removal of the known cumulus records probably exaggerates the effects of cloud collision warning radar, since an aircraft with radar flying in similar conditions might have flown through some lesser disturbances while making a detour around the severe turbulence.

Bullen and Judy Aplin[8] compared the accelerometer records from Viscount operations with and without radar, which constituted a more precise comparison than is possible between the different Comet fleets. The Viscount was flying in Africa and at lower altitude than the Comets so that it encountered more turbulence. In order to compare these results, reduction ratios of gust frequencies for the Viscounts with radar to those without radar was applied to the Comet 1 and the frequency distribution obtained was approximately that of the later types of Comet.

4.4 Variations with altitude

The relative frequencies of up and down loads exceeding 4 m/s is shown in Fig.10 together with the empirical expression proposed by Bullen[11]. A general decrease in the ratio with altitude is detectable but above 10000 ft the variations for each fleet show no consistent trends, this may be influenced by different operating techniques.

In Fig.11 the frequencies of 4 m/s and 6 m/s gusts (based on spectral factors) have been plotted against altitude. Altitude bands have been combined if the recorded distances were considered insignificant. The three major flight conditions have been combined and the initial climb and final descent

records have been ignored. The curves for the civil and military fleets are seen to be distinct, most particularly at lower altitudes, which was also noted for the gust frequency distributions. The Comets 1 and 2 both show an increase in gust frequency at altitudes greater than the normal cruise, this being most marked for the more severe turbulence. This is mainly explained by the operational technique of changing height to avoid some areas of turbulence; the increase is not observed on the later aircraft, suggesting that height holding requirements were more rigid.

4.5 Variations between individual aircraft

The Comet 1 fleet had counting accelerometers fitted on three aircraft, the Comet 4 fleet two aircraft and the Comet 4C only one aircraft. Seven Comet 2s were equipped with instruments, so that the records on the individual aircraft of this fleet were too small to justify separate study.

Table 4 subdivides the distance flown by each aircraft according to the zone. Apart from the 75000 km recorded on G-APDA while flying on routes in the Western hemisphere, the geographical distributions of the data for this and the other Comet 4 (G-APDB) are similar, also, the individual Comet 1 aircraft each visited different parts of the world in nearly the same pattern. The seasonal distributions of the data for the former type are similar but G-ALYS was the only Comet 1 to have yielded observations for the whole year. The other two aircraft records introduce some bias, since they are concentrated between the months August to December. Within this restriction it may be expected that the five BOAC aircraft flew through atmospheric samples of similar characteristics, after excluding from the Comet 1 data that turbulence known to have been in the vicinity of cumulus activity.

Fig.12 compares the aircraft of the Comet 1 and Comet 4 fleets for cruising flight higher than 29750 ft and for climb and descent between 5750 and 29750 ft. The lines have been drawn up to the highest gust speeds at which four or more gusts had been counted. G-APDB encountered gusts at between two and three times the frequency of the other Comet 4 during cruise and between three and four times the frequency in climb and descent. This consistent discrepancy is rather more than would have been expected for this quantity of data had it been recorded from flying over the same route and season pattern by identical aircraft and instruments. The ranges of gust frequencies corresponding to gust counts within two standard deviations

of the observed value were calculated by the method of Bullen[9] for both aircraft and the ranges for climb and descent were found to be distinct up to a gust speed of 4 m/s. For the cruise data this level of significance did not extend to gust speeds of 3 m/s, there being fewer gusts counted under these flight conditions and consequently wider significance limits.

Sturgeon[10] has described differences of this type for two nominally identical aircraft. The accelerometer on one recorded double the number of low magnitude loads counted on the other aircraft and, since analogue traces were also available, a more severe autopilot hunting could be detected in the motion of the 'rogue' aircraft. It was stated that this contributed to the moderate loads but had no detectable effect on the severe loads, these occur so infrequently that differences between these loads would have little statistical significance. The Comet 4s studied here might have displayed similar differences in autopilot behaviour if the appropriate data had been available.

The Comet 1 data do not show such significant differences between aircraft. The gust frequency curves for the cruise are very close to the mean for the fleet and the variations at higher gust speeds during climb and descent have no statistical significance. As stated earlier in this section, seasonal factors may have affected the relationship between the loads recorded on each Comet 1 and so it cannot be deduced from the results that there were no significant differences between the turbulence response of the individual aircraft.

5 CONCLUSIONS

Analysis of the counting accelerometer data from the operation of four marks of Comet aircraft has shown that the magnitude and number of loads recorded differed considerably between the distinct types of operations covered.

Comet 1 and Comet 4 records for civil flying were found to be closely comparable after removing from the Comet 1 data all encounters with turbulence known to be in the vicinity of cumulus clouds. This implies that the cloud collision warning radar on the Comet 4 was used successfully to avoid areas of cumulus activity.

Significant discrepancies between the two individual aircraft were found in the Comet 4 observations. It is possible that this might be explained in terms of differences in aircraft dynamics, such as autopilot behaviour.

The Comet 2 and 4C flying military transport services encountered fewer gusts than the civil aircraft. This applied both to individual phases of flight and particularly to the gust frequencies measured during all flying, since a greater proportion of the total time was spent at high altitude with consequently less frequent turbulence encounters.

Table 1

AIRCRAFT CHARACTERISTICS

The following values were assumed to apply approximately to all Comet aircraft, except for wing area.

Wing span		35 m
Wing area	Comet 1	187 sq m
	Comet 2	188 sq m
	Comet 4 and 4C	197 sq m

Low speed slope of the lift curve	4.8 per radian
Maximum value of slope of the lift curve (at Mach number 0.79)	6.40 per radian
Gust gradient distance for discrete gust response calculations	37 m

Table 2

IDENTIFICATION OF ALTITUDE BAND NUMBERS

Band number	Altitude (ft)
1	0 - 1750
2	1750 - 3750
3	3750 - 5750
4	5750 - 9750
5	9750 - 13750
6	13750 - 17750
7	17750 - 21750
8	21750 - 25750
9	25750 - 29750
10	29750 - 33750
11	33750 - 37750
12	37750 - 41750
13	Above 41750

Table 3a

DETAILS OF RECORDED FLYING IN ALL FLIGHT CONDITIONS BOAC AIRCRAFT

Altitude band	Distance km	Time min	Mean conditions			Mean gust speed (m/s) corresponding to 1 g acceleration	
			Altitude ft	Speed knots EAS	Mass parameter	Discrete	Continuous
Comet 1							
1	301	65	1000	148	12.1	11.3	17.7
2	2 298	445	2600	161	12.6	10.3	16.2
3	6 527	1150	4700	171	14.3	10.0	15.6
4	33 623	5055	7700	217	16.0	8.9	14.0
5	34 466	4470	11400	210	18.0	8.0	12.7
6	37 428	4435	15700	214	20.8	7.7	12.3
7	46 485	5210	19600	212	23.6	7.7	12.3
8	60 666	6476	23600	208	27.0	7.7	12.4
9	83 936	8500	27700	204	31.1	7.8	12.5
10	281 308	25360	31900	212	34.9	7.1	11.6
11	470 711	9680	35400	212	36.1	6.4	10.7
12	94 805	7615	38600	207	37.8	6.0	10.2
13	744	60	42800	186	42.8	6.0	10.7
Comet 4							
1	3 618	747	1100	154	17.4	14.9	21.2
2	9 474	1648	2700	179	18.8	13.2	19.4
3	7 918	1194	4700	200	19.9	11.6	17.1
4	16 942	2187	7800	223	21.9	10.3	15.2
5	17 933	2002	11700	242	24.9	9.5	14.0
6	21 198	2160	15900	248	28.3	9.1	13.4
7	26 050	2490	19900	248	31.6	8.8	13.1
8	29 094	2533	23700	255	35.3	8.4	12.5
9	57 141	4565	28200	256	27.6	7.6	11.6
10	351 792	25303	32100	265	40.4	7.0	10.5
11	353 823	25138	34700	255	43.5	7.0	10.7
12	15 159	1167	38500	228	46.8	7.0	11.1

Table 3b

DETAILS OF RECORDED FLYING IN ALL FLIGHT CONDITIONS RAF AIRCRAFT

Altitude band	Distance km	Time min	Mean conditions			Mean gust speed (m/s) corresponding to 1 g acceleration	
			Altitude ft	Speed knots EAS	Mass parameter	Discrete	Continuous
Comet 2							
1	990	207	1300	152	14.1	12.2	18.6
2	4 643	832	2600	174	15.9	11.4	17.3
3	2 103	336	4700	189	15.1	9.5	14.7
4	6 833	919	7700	214	18.6	9.1	14.0
5	7 357	906	11900	219	21.0	8.6	13.2
6	7 717	880	15900	222	24.0	8.4	13.0
7	10 728	1156	19800	220	27.0	8.3	12.9
8	11 991	1192	23700	223	31.6	8.2	12.8
9	14 428	1341	27800	222	34.8	7.8	12.4
10	24 817	2148	31900	221	39.2	7.6	12.0
11	101 708	7867	36500	226	41.3	6.6	10.7
12	273 121	20587	39900	214	42.0	6.1	10.2
13	29 481	2243	42500	199	45.1	6.1	10.4
Comet 4C							
1	2 709	608	1000	142	17.6	16.5	23.3
2	3 383	626	2600	168	18.0	13.5	20.0
3	2 435	356	4700	207	20.8	11.7	17.0
4	5 769	722	7600	231	22.1	10.1	14.9
5	5 742	620	11700	251	26.3	9.6	14.0
6	5 883	588	15800	253	29.1	9.1	13.5
7	6 729	625	19700	256	33.8	9.1	13.4
8	8 976	770	24100	257	37.1	8.6	12.7
9	27 035	2083	28300	265	37.9	7.4	11.2
10	146 941	10673	32100	262	40.8	7.1	10.7
11	171 098	12318	34700	252	42.3	6.9	10.6
12	1 705	115	38000	250	64.8	9.0	12.8

Table 4

GEOGRAPHICAL DISTRIBUTION OF FLYING DISTANCE RECORDED ON INDIVIDUAL AIRCRAFT (km)

Zone number	Zone	Comet 1			Comet 2 (all aircraft)	Comet 4		Comet 4C
		G-ALYS	G-ALYX	G-ALYW		G-APDA	G-APDB	
0	Europe	233 997	106 546	47 407	141 347	107 157	55 457	127 925
1	Indian Ocean				126 887	34 116	17 948	171 125
2	Africa	220 894	95 372	36 970	74 424	87 770	99 081	
3	Middle and Far East	243 411	84 238	51 687	115 903	181 766	161 333	89 355
4	Australasia				11 056	50 121	29 184	
5	North Atlantic				8 671	39 611		
6	Pacific	25 900	6 877		6 285	3 857	6 694	
7	North America				11 348			
8	South America					36 049		
	Total	724 202	293 033	136 064	495 918	540 447	369 697	388 405

Table 5

COMET 1 ACCELERATION DATA

Flight condition	Altitude band	Distance km	Time minutes	Number of times each acceleration increment (g) was exceeded															
				Down								Up							
				0.92	0.82	0.72	0.62	0.52	0.43	0.33	0.23	0.23	0.33	0.43	0.52	0.62	0.72	0.82	0.92
Climb and descent	1	300	65								1	11	7						
	2	2 298	445		2	6	5	7	11	32	78	216	78	15	10	2	2		
	3	6 527	1150				1	4	14	75	225	454	145	40	14	3	2		
	4	33 623	5055		1	5	8	22	76	364	987	1873	691	212	69	21	11	3	1
	5	34 466	4470	1	1	3	5	13	31	151	444	733	247	63	16	8	3	2	
	6	37 428	4435	1	3	5	6	14	26	93	216	343	136	45	21	8	3		
	7	46 485	5210			1	3	7	18	63	152	272	97	35	17	9	4	1	
	8	60 500	6455	1	2	2	2	5	11	41	120	214	60	17	7	1	1	1	1
	9	78 844	8030				2	2	8	46	161	203	52	12	6	2			
	10	81 401	7825				1	5	11	31	111	184	62	20	6	3	3	1	1
	11	33 911	2960	1	1	1	2	4	8	29	86	114	39	9	3	1			
	12	2 237	180								1	1							
	TOTAL	418 020	46280	4	10	23	35	83	214	925	2582	4618	1614	468	169	58	29	8	3
Cruise	8	166	21																
	9	5 092	470						4	7	15	29	14	10	5	2	1		
	10	199 907	17535	1	1	3	6	10	20	74	262	332	85	20	9	7	6	2	1
	11	436 800	36720	5	7	15	24	62	134	428	946	1259	455	171	84	43	31	19	5
	12	92 569	7435			1	3	8	15	59	179	268	82	20	9	2	1		
	13	744	60								3	8	2						
	TOTAL	735 279	62241	6	8	19	33	80	173	568	1405	1896	638	221	107	54	39	21	6

Table 6a

COMET 2 ACCELERATION DATA

Flight condition	Altitude band	Distance km	Time minutes	Number of times each acceleration increment (g) was exceeded												
				Down							Up					
				1.2	1.0	0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
Initial climb	1	284	51					3	12	35	48	21	5	1		
	2	2 534	438			1	2	23	83	313	500	158	39	4	2	
	3	186	31					1	7	33	42	11	2			
	TOTAL	3 005	520			1	2	27	102	381	590	190	46	5	2	
Final descent	1	635	141						2	20	71	7	2			
	2	1 252	237					1	20	75	172	54	10	1		
	3	397	68						3	21	39	9				
	4	303	48							2	13	6	2			
	TOTAL	2 587	494					1	25	118	295	76	14	1		
Climb and descent	2	350	62							1	14	1				
	3	1 317	205					1	5	36	58	13	4			
	4	6 470	862					6	22	125	178	42	13			
	5	7 303	899						6	48	85	15	3			
	6	7 648	872					1	7	38	57	9	2			
	7	9 949	1064						3	29	29	3	1			
	8	11 469	1139					2	10	24	21	1				
	9	14 396	1338						4	19	17	2				
	10	22 220	1940						3	26	40	3				
	11	24 696	2002					9	35	105	112	41	13			
	12	19 873	1543					6	40	128	151	38	11			
	13	1 924	150					1	3	4	8	2	1			
	TOTAL	127 615	12076					26	138	583	770	170	48			

Table 6b

COMET 2 ACCELERATION DATA

Flight condition	Altitude band	Distance km	Time minutes	Number of times each acceleration increment (g) was exceeded												
				Down							Up					
				1.2	1.0	0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
Cruise	1	71	15													
	2	507	95						1	9	29	2				
	3	203	32							1	4					
	4	60	9								1					
	5	54	7								1					
	6	68	8													
	7	779	92								4					
	8	523	53							1	1					
	9	33	3													
	10	2 597	208							6	5	1				
	11	77 013	5865						3	68	73	12	4			
	12	253 248	19044	1	1	3	4	31	109	527	602	140	43	9	3	1
	13	27 557	2093				1	3	12	76	122	28	3			
	TOTAL	362 711	27524	1	1	3	5	34	125	688	842	183	50	9	3	1

Table 7a

COMET 4 ACCELERATION DATA

Flight condition	Altitude band	Distance km	Time minutes	Number of times each acceleration increment (g) was exceeded								
				Down				Up				
				0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8
Initial climb	1	1 232	218			8	139	171	17	1		
	2	4 575	749		8	31	365	513	81	13	1	
	3	1 376	216		1	18	172	245	57	5		
	TOTAL	7 184	1183		9	57	676	929	155	19	1	
Landing	1	940	226				15	25	3	1		
Climb and descent	1	1 323	278			3	55	95	14	3		
	2	4 265	778			6	269	393	77	7		
	3	6 068	899		8	24	417	538	97	19	2	
	4	16 450	2114	1	17	81	996	1192	212	32	2	
	5	17 849	1990		13	54	530	558	69	13	2	
	6	20 996	2138		11	36	344	424	69	10	2	
	7	24 603	2356		6	17	244	231	31	5	2	
	8	28 327	2463			7	211	193	31	7	1	1
	9	52 123	4160			8	220	128	15	2		
	10	94 000	7028	1	22	65	585	413	57	18	5	
	11	33 419	2434		6	23	122	126	29	8	1	1
	12	1 917	138			3	16	10	1			
	TOTAL	301 341	26776	2	83	327	4009	4301	702	124	17	2

Table 7b

COMET 4 ACCELERATION DATA

Flight condition	Altitude band	Distance km	Time minutes	Number of times each acceleration increment (g) was exceeded								
				Down				Up				
				0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8
Cruise	1	123	25				2	10				
	2	633	121			6	113	34	5			
	3	474	79			2	50	53	4			
	4	472	70				51	72	9			
	5	64	9					2				
	6	172	18				5	43				
	7	1 447	134				10	5	2			
	8	767	70			1	6	9				
	9	5 018	405			1	6	34	4			
	10	257 791	18275		22	63	754	441	69	16		
	11	320 404	22704		10	80	939	878	105	24	3	
	12	13 243	969				3	1				
	TOTAL	600 608	42879		32	153	1939	1582	198	40	3	

Table 8a

COMET 4C ACCELERATION DATA

Flight condition	Altitude band	Distance km	Time min	Number of times each acceleration increment (g) was exceeded									
				Down					Up				
				0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8
Initial climb	1	866	180				1	26	48	4			
	2	686	141				2	12	17	4			
	3	22	4						1				
	Total	1574	325				3	38	66	8			
Landing	1	967	243										
Climb and descent	2	1199	197					3	7				
	3	2070	298			1	2	17	31	4	1		
	4	5390	672			3	5	46	56	8	2		
	5	5524	595			1	4	24	23	7	3		
	6	5799	579				1	13	23	3			
	7	6527	606			1	4	14	19	5	1	1	1
	8	8880	762				1	8	9	1	1		
	9	13801	1100				2	9	9	1			
	10	27558	2064			1	5	42	44	10			
	11	5955	429					4	7				
	Total	82703	7302			7	24	180	228	39	8	1	1

Table 8b

COMET 4C ACCELERATION DATA

Flight condition	Altitude band	Distance km	Time min	Number of times each acceleration increment (g) was exceeded									
				Down					Up				
				0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8
Cruise	1	887	185				1	4	16				
	2	1 498	288			1	1	16	48	12	2		
	3	342	54					1	10				
	4	379	50			2	5	13	21	4	1		
	5	218	25					1					
	6	84	9						2				
	7	201	19										
	8	96	8										
	9	13 234	983		7	26	60	156	114	64	31	4	1
	10	119 384	8609				7	70	94	11	1		
	11	165 144	11889	1	1	5	27	163	136	23	5	1	
	12	1 705	115				1	3	3	1			
	Total	303 160	22234	1	8	34	102	427	444	115	40	5	1

Table 9

GUSTS ENCOUNTERED BY COMET 1, DISCRETE RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded								Gust speed m/s EAS									
				Down									Up								
				9	8	7	6	5	4	3.5	3	2.5	2.5	3	3.5	4	5	6	7	8	9
Climb and descent	1	300	65									1	11	9	7	2					
	2	2 298	445		1	5	6	9	18	30	48	76	194	116	64	34	13	4	1		
	3	6 527	1150				1	4	26	57	113	202	382	223	135	78	26	11	4	3	2
	4	33 623	5055		1	5	9	29	97	189	361	647	1193	684	374	206	60	26	7	3	
	5	34 466	4470	1	1	1	3	8	32	57	111	229	359	187	94	43	13	3			
	6	37 428	4435		1	2	4	7	15	27	50	100	164	86	38	22	8	1			
	7	46 485	5210				2	3	10	22	40	67	110	61	34	21	10	2	1	1	
	8	60 500	6455			1	2	2	5	10	20	40	62	29	16	9	2	1			
	9	78 844	8030					2	4	9	24	49	55	24	11	7	2				
	10	81 401	7825					2	7	10	18	36	63	30	16	10	4	3	1	1	
	11	33 911	2960					1	2	4	7	13	18	8	3						
	12	2 237	180																		
	Total	418 020	46280	1	4	14	28	67	215	414	793	1459	2609	1458	791	430	138	50	15	7	2
Cruise	8	166	21																		
	9	5 092	470							1	4	6	14	11	7	4	1				
	10	199 907	17535			1	1	3	9	14	25	59	72	29	12	9	6	3	1		
	11	436 800	36720			2	2	8	34	65	137	265	315	168	92	54	22	7			
	12	92 569	7435					2	3	7	14	30	40	15	9	4	1				
	13	744	60																		
	Total	735 279	62241			3	3	13	46	87	179	360	441	223	120	70	30	9	1		

Table 10a

GUSTS ENCOUNTERED BY COMET 2, DISCRETE RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded — Down										Gust speed m/s EAS — Up									
				10	9	8	7	6	5	4	3.5	3	2.5	2.5	3	3.5	4	5	6	7	8	9	10
Initial climb	1	284	51				1	2	5	13	19	28	43	54	38	28	21	8	4	3	2	1	1
	2	2 534	438	1	1	2	3	10	22	59	100	171	300	481	294	184	105	36	16	6	3	2	2
	3	186	31							2	5	11	24	32	17	9	4	1					
	Total	3 005	520	1	1	2	4	12	28	74	124	210	366	567	349	221	130	45	21	8	5	3	3
Final descent	1	635	141							1	2	6	16	63	27	9	4	2	1				
	2	1 252	237							2	8	19	39	101	57	26	11	3	1				
	3	397	68							1	3	5	11	26	14	7	3						
	4	303	48											7	5	3	2						
	Total	2 587	494							4	13	31	66	197	102	45	19	5	1				
Climb and descent	2	350	62											6	1								
	3	1 317	205								1	3	8	17	9	4	1						
	4	6 470	862					1	3	7	14	22	40	70	34	17	7	1					
	5	7 303	899								1	4	9	19	6	3	2						
	6	7 648	872							1	2	3	9	15	6	3	2	1					
	7	9 949	1064									1	4	3	1								
	8	11 469	1139							1	2	5	8	1									
	9	14 396	1338										1	1									
	10	22 220	1940										2	2									
	11	24 696	2002							1	3	8	19	23	10	4	1						
	12	19 873	1543								2	5	15	18	8	3							
	13	1 924	150									1	1	2	1								
	Total	127 615	12076					1	3	11	25	52	116	176	78	34	14	2					

Table 10b

GUSTS ENCOUNTERED BY COMET 2, DISCRETE RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded							Gust speed m/s EAS					
				Down							Up					
				7	6	5	4	3.5	3	2.5	2.5	3	3.5	4	5	6
Cruise	1	71	15													
	2	507	95						1	4	15	5	2	1		
	3	203	32							1	2					
	4	60	9													
	5	54	7													
	6	68	8													
	7	779	92													
	8	523	53													
	9	33	3													
	10	2 597	208								1					
	11	77 013	5865								5	2	1			
	12	253 248	19044	1	1	3	5	9	18	34	50	22	11	6	3	1
	13	27 557	2093				1	2	3	6	7	3	1			
	Total	362 711	27524	1	1	3	6	11	23	45	79	33	14	7	3	1

Table 11a

GUSTS ENCOUNTERED BY COMET 4, DISCRETE RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded — Down: 7	6	5	4	3.5	3	2.5	Gust speed m/s EAS — Up: 2.5	3	3.5	4	5	6	7	8	9
Initial climb	1	1 232	218			2	27	65	132	230	312	178	92	44	9	1			
	2	4 575	749	1	4	10	43	106	254	560	671	359	185	95	25	8	4	2	1
	3	1 376	216		1	2	13	33	83	192	261	136	80	47	12	2			
	Total	7 184	1183	1	5	14	83	205	469	982	1244	674	357	186	46	11	4	2	1
Landing	1	940	226				2	6	14	25	40	24	13	7	2	1	1		
Climb and descent	1	1 323	278			1	7	21	47	88	154	81	40	18	5	2	1		
	2	4 265	778				7	37	123	285	398	212	110	56	12	2			
	3	6 068	899		1	6	28	62	139	313	439	228	119	56	9	3	1		
	4	16 450	2114		1	5	35	83	184	454	668	325	161	79	25	11	4	2	1
	5	17 849	1990		1	3	9	20	55	166	195	67	26	12	4	2			
	6	20 996	2138			2	6	12	28	70	113	45	18	9	2				
	7	24 603	2356			1	5	9	15	34	50	25	13	6	2	1	1	1	
	8	28 327	2463						2	9	25	10	5	3	1	1	1		
	9	52 123	4160						1	6	11	3	1	1					
	10	94 000	7028			1	9	16	24	43	43	25	15	10	4	1			
	11	33 419	2434						2	7	10	3	1	1	1				
	12	1 917	138																
	Total	301 341	26776	1	3	18	107	260	621	1476	2106	1025	510	250	65	22	8	3	1

Table 11b

GUSTS ENCOUNTERED BY COMET 4, DISCRETE RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded Gust speed m/s EAS															
				Down							Up								
				7	6	5	4	3.5	3	2.5	2.5	3	3.5	4	5	6	7	8	9
Cruise	1	123	25						1	3	13	6	2						
	2	633	121			1	6	17	48	129	38	20	10	4	1				
	3	474	79				1	4	14	38	45	18	6	2					
	4	472	70					3	18	50	73	34	15	6					
	5	64	9								2								
	6	172	18																
	7	1 447	134								2	1							
	8	767	70							1									
	9	5 018	405																
	10	257 791	18275				5	12	26	50	54	23	9	3					
	11	320 404	22704					2	6	29	44	16	8	4					
	12	13 243	969																
	TOTAL	600 608	42879			1	12	39	114	300	271	118	50	20	1				

Table 12a

GUSTS ENCOUNTERED BY COMET 4C AIRCRAFT, DISCRETE RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded						Gust speed m/s EAS							
				Down						Up							
				6	5	4	3.5	3	2.5	2.5	3	3.5	4	5	6	7	8
Initial climb	1	866	180		4	20	33	50	70	124	88	59	36	9	2		
	2	686	141	1	3	8	13	19	27	34	24	17	11	4	1		
	3	22	4							2	1	1					
	Total	1574	325	1	7	28	45	69	97	159	113	76	47	13	3		
Landing	1	967	243														
Climb and descent	2	1199	197					1	1	7	3	1					
	3	2070	298		1	2	3	5	12	19	8	5	3	1			
	4	5390	672			2	5	9	21	22	11	6	3				
	5	5524	595			1	1	3	9	10	6	3	2				
	6	5799	579						2	5	1						
	7	6527	606			2	3	5	8	8	4	2	1	1	1	1	1
	8	8880	762						1	1	1	1	1	1			
	9	13801	1100					1	2	1	1						
	10	27558	2064					1	3	5							
	11	5955	429														
	Total	82703	7302		1	6	12	24	59	78	34	18	10	3	2	1	1

Table 12b

GUSTS ENCOUNTERED BY COMET 4C AIRCRAFT - DISCRETE RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded Gust speed m/s EAS													
				Down						Up							
				6	5	4	3.5	3	2.5	2.5	3	3.5	4	5	6	7	8
Cruise	1	877	185			1	2	3	6	21	10	3					
	2	1498	288	1	1	1	3	8	18	52	31	17	10	3	1		
	3	342	54						1	9	3						
	4	379	50			1	2	4	7	10	4	2	1				
	5	218	25														
	6	84	9														
	7	201	19														
	8	96	8														
	9	13 234	983	1	7	15	22	31	47	59	38	22	12	4	2	1	
	10	119 384	8609						2	4	1						
	11	165 144	11889	1	1	1	2	6	15	13	5	3	2				
	12	1 705	115														
	Total	303 160	22234	3	9	19	31	53	96	168	91	47	25	7	3	1	

Table 13

GUSTS ENCOUNTERED BY COMET 1, SPECTRAL RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded													Gust speed m/s EAS						
				Down										Up			Up						
				14	12	10	9	8	7	6	5	4	3	3	4	5	6	7	8	9	10	12	14
Climb and descent	1	300	65									1	2	15	11	8	4						
	2	2 298	445		3	6	6	9	12	22	42	73	143	369	190	99	45	21	12	5	2		
	3	6 527	1150				1	4	11	35	90	193	385	769	370	188	97	47	24	14	8	3	2
	4	33 623	5055		3	7	12	26	57	130	304	640	1333	2397	1178	582	274	129	59	33	19	4	
	5	34 466	4470	1	1	3	4	8	20	40	90	224	512	802	357	157	64	27	12	5	2		
	6	37 428	4435		1	4	5	6	11	21	42	104	203	365	169	73	30	16	8	3			
	7	46 485	5210			1	3	3	5	16	34	69	137	262	116	55	26	17	11	5	2	1	
	8	60 500	6455		1	2	2	2	4	8	17	42	106	182	65	26	12	5	1	1	1		
	9	78 844	8030				1	2	2	6	21	53	131	175	60	21	9	5	2	1			
	10	81 401	7825				1	2	5	9	17	39	97	159	70	29	14	8	5	3	3	1	
	11	33 911	2960				1	1	2	3	7	17	52	59	22	8	2						
	12	2 237	180																				
	Total	418 020	46280	1	8	23	36	64	130	289	664	1453	3102	5555	2608	1247	577	276	134	70	38	10	3
Cruise	8	166	21																				
	9	5 092	470								5	7	13	26	15	11	7	3	2	1			
	10	199 907	17535		1	1	1	3	6	12	23	66	188	229	79	27	10	8	6	4	2	1	
	11	436 800	36720		1	3	7	13	27	58	138	321	721	932	373	170	85	48	30	17	7		
	12	92 569	7435				1	2	2	7	15	40	101	157	54	16	9	3	1				
	13	744	60											3									
	Total	735 279	62241		2	4	9	18	36	78	181	434	1024	1347	521	223	110	62	39	21	9	1	

Table 14

GUSTS ENCOUNTERED BY COMET 2 AIRCRAFT, SPECTRAL RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded — Down: 14	12	10	9	8	7	6	5	4	3	Gust speed m/s EAS — Up: 3	4	5	6	7	8	9	10	12	14
Initial climb	1	284	51			1	2	4	6	12	20	35	64	76	46	30	19	10	6	4	3	2	1
	2	2 534	438	1	2	4	9	17	27	56	113	241	492	774	397	207	99	45	28	15	7	3	2
	3	186	31						1	2	7	19	48	64	26	12	4	2	1				
	Total	3 005	520	1	2	5	11	21	34	70	140	295	604	914	469	248	122	56	34	19	10	5	3
Final descent	1	635	141							1	4	13	34	137	56	17	4	2	2	1			
	2	1 252	237						1	3	14	35	83	203	93	42	14	5	2	1			
	3	397	68							1	4	10	29	55	24	11	4	1					
	4	303	48										1	12	7	4	2	1					
	Total	2 587	494						1	6	22	58	147	408	181	74	24	9	4	2	1		
Climb and descent	2	350	62										1	17	5	1							
	3	1 317	205								2	7	29	47	16	7	2						
	4	6 470	862					2	4	7	17	34	102	169	59	23	9	3	1				
	5	7 303	899								2	8	30	67	16	5	2	1					
	6	7 648	872						1	1	2	8	27	43	14	5	2	1	1				
	7	9 949	1064									3	12	13	2	1							
	8	11 469	1139							1	3	8	16	9	1								
	9	14 396	1338									1	7	6	1								
	10	22 220	1940									2	11	18	2								
	11	24 696	2002							2	7	21	56	62	25	9	2						
	12	19 873	1543							1	4	17	58	62	20	7	2						
	13	1 924	150								1	1	3	3	2	1							
	Total	127 615	12076				1	2	5	13	39	109	353	516	162	58	20	6	2				

Table 14b

GUSTS ENCOUNTERED BY COMET 2 AIRCRAFT, SPECTRAL RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded													Gust speed m/s EAS					
				Down									Up									
				12	10	9	8	7	6	5	4	3	3	4	5	6	7	8	9	10	12	14
Cruise	1 2 3	71 507 203	15 95 32							1	3 1	12 2	42 6	13 2	3	1						
	4 5 6	60 54 68	9 7 8										1									
	7 8 9	779 523 33	92 53 3										1									
	10 11	2 597 77 013	208 5865									3 5	3 16	1 5	2							
	12 13	253 248 27 537	19044 2093	1	1	2	3	4 1	8 1	19 3	42 8	167 27	199 44	60 10	23 3	11	6	3	2	1		
	Total	362 711	27524	1	1	2	3	5	9	23	53	215	312	90	32	12	6	3	2	1		

Table 15a

GUSTS ENCOUNTERED BY COMET 4 AIRCRAFT, SPECTRAL RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded								Gust speed m/s EAS									
				Down								Up									
				10	9	8	7	6	5	4	3	3	4	5	6	7	8	9	10	12	14
Initial climb	1	1 232	218				3	18	64	167	334	466	224	92	32	11	3	1			
	2	4 575	749	1	3	6	12	33	112	366	1070	1120	483	194	78	31	13	7	4	1	1
	3	1 376	216		1	1	2	11	38	130	381	517	188	86	42	16	5	2			
	TOTAL	7 184	1183	2	4	8	18	61	215	663	1784	2103	895	372	151	57	20	9	4	1	1
Landing	1	940	226					2	8	21	40	58	31	13	6	3	1	1	1		
Climb and descent	1	1 323	278				1	4	21	60	129	221	97	40	15	7	3	2	1		
	2	4 265	778				1	6	53	212	530	694	317	133	53	19	5	2	1		
	3	6 068	899		1	3	11	28	80	234	656	817	344	145	54	16	5	2	1		
	4	16 450	2114		1	2	10	35	106	321	1123	1419	515	201	79	35	19	11	6	2	1
	5	17 849	1990		1	2	4	9	29	111	495	549	136	36	13	6	3	2	1		
	6	20 996	2138			1	3	6	16	49	215	293	84	25	9	4	2				
	7	24 603	2356				2	6	10	25	114	135	40	18	7	3	2	1	1	1	
	8	28 327	2463							5	54	83	18	6	3	1	1	1	1		
	9	52 123	4160							3	38	37	7	2	1						
	10	94 000	7028				3	9	19	36	122	99	36	19	10	6	3	1			
	11	33 419	2434						1	6	26	35	8	2	1	1					
	12	1 917	138								4	2									
	TOTAL	301 341	26776	1	3	9	35	104	336	1062	3506	4385	1601	626	244	98	44	23	12	3	1

Table 15b

GUSTS ENCOUNTERED BY COMET 4 AIRCRAFT, SPECTRAL RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded					Gust speed m/s EAS					
				Down					Up					
				7	6	5	4	3	3	4	5	6	7	8
Cruise	1	123	25			1	2	5	23	11	3			
	2	633	121	1	5	23	91	363	64	30	12	4	2	1
	3	474	79		1	6	25	88	89	31	8	2		
	4	472	70			6	38	99	147	58	20	7	1	
	5	64	9						3	1				
	6	172	18						4					
	7	1 447	134					2	4	2				
	8	767	70				1	4	4					
	9	5 018	405					1	4					
	10	257 791	18275	1	5	18	41	129	135	43	13	4		
	11	320 404	22704		1	3	19	129	156	32	12	4	1	
	12	13 243	969					1						
	TOTAL	600 608	42879	2	12	57	217	822	633	207	68	20	4	1

Table 16a

GUSTS ENCOUNTERED BY COMET 4C AIRCRAFT, SPECTRAL RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded — Down 8	7	6	5	4	Gust speed m/s EAS 3	Up 3	4	5	6	7	8	9	10
Initial climb	1	866	180	1	5	14	30	54	86	153	97	55	25	9	4	1	
	2	686	141	1	3	6	13	22	35	43	28	17	9	5	2		
	3	22	4							3	2	1					
	TOTAL	1574	325	2	7	20	43	76	120	199	127	72	35	13	5	2	
Landing	1	967	243														
Climb and descent	2	1199	197					1	4	14	5	1					
	3	2070	298	1	1	2	3	9	26	39	13	5	3	1	1		
	4	5390	672		1	2	5	14	47	51	15	7	2				
	5	5524	595			1	1	6	19	20	9	4	2	1			
	6	5799	579					1	6	12	3						
	7	6527	606			1	3	6	14	18	7	2	1	1	1	1	1
	8	8880	762					1	4	3	1	1	1	1			
	9	13801	1100					1	5	3	1						
	10	27558	2064				1	3	14	18	4						
	11	5955	429						1	1							
	TOTAL	82703	7302	1	2	5	14	42	139	177	59	20	9	4	2	1	1

Table 16b

GUSTS ENCOUNTERED BY COMET 4C AIRCRAFT, SPECTRAL RESPONSE FACTOR

Flight condition	Altitude band	Distance km	Time min	Number of times each gust speed was exceeded								Gust speed m/s EAS							
				Down								Up							
				10	9	8	7	6	5	4	3	3	4	5	6	7	8	9	10
Cruise	1	877	185					1	2	5	9	36	17	5					
	2	1 498	288		1	1	1	1	5	14	34	83	44	20	10	4	2	1	
	3	342	54							1	2	18	6	1					
	4	379	50					1	3	6	12	21	7	2	1				
	5	218	25																
	6	84	9																
	7	201	19																
	8	96	8																
	9	13 234	983		1	5	9	15	25	41	86	71	53	27	12	6	3	2	1
	10	119 384	8609							1	13	19	2						
	11	165 144	11889		1	1	1	2	4	12	51	40	10	4	2	1			
	12	1 705	115								2	2							
	TOTAL	303 160	22234	1	3	7	11	19	38	79	208	291	139	60	26	11	5	3	1

Table 17

NUMBERS OF EXCEEDANCES RECORDED ON COMET 1 IN THE VICINITY OF CUMULUS CLOUD

Flight condition	Altitude band	Distance km	Time min	Down						Accelerations, g									Up
				0.92	0.82	0.72	0.62	0.52	0.43	0.33	0.23	0.23	0.33	0.43	0.52	0.62	0.72	0.82	0.92
Climb and descent	8	89	10								1	3	1	1	1				
	9	482	50				1	1	4	18	35	47	13	4	2	1			
	11	338	30	1	1	1	2	3	7	22	44	46	24	8	3	1			
Cruise	10	831	80	1	1	1	1	1	5	17	69	78	25	5	3	2	2	1	1
	11	5251	480	5	7	15	21	57	112	337	617	774	336	142	73	39	28	18	5
	12	813	70			1	2	5	12	30	59	64	36	13	7	1			

Flight condition	Altitude band	Down						Gust speed, m/s EAS		Discrete gust response factor							Up
		7	6	5	4	3.5	3.0			2.5	2.5	3.0	3.5	4	5	6	7
Climb and descent	8										2	1	1	1			
	9			1	3	6	13			18	15	8	5	3	1		
	11			1	2	4	6			12	12	5	2				
Cruise	10	1	1	1	2	4	10			22	32	14	5	3	2	2	1
	11	2	2	8	31	58	121			217	252	142	79	47	20	7	
	12			2	3	5	11			22	24	12	7	2			

Flight condition	Altitude band	Down								Gust speed, m/s EAS	Spectral response factor							Up	
		12	10	9	8	7	6	5	4		3	3	4	5	6	7	8	9	10	12
Climb and descent	8										1	4	2	1	1	1				
	9				1	1	4	12	19		25	38	16	8	4	2	1	1		
	11			1	1	2	4	7	15		31	32	15	6	2					
Cruise	10	1	1	1	1	1	3	9	24		75	81	35	13	4	3	2	2	2	1
	11	1	3	7	13	25	55	126	264		546	670	301	147	75	43	28	16	7	
	12			1	2	2	5	12	28		49	54	28	14	7	2				

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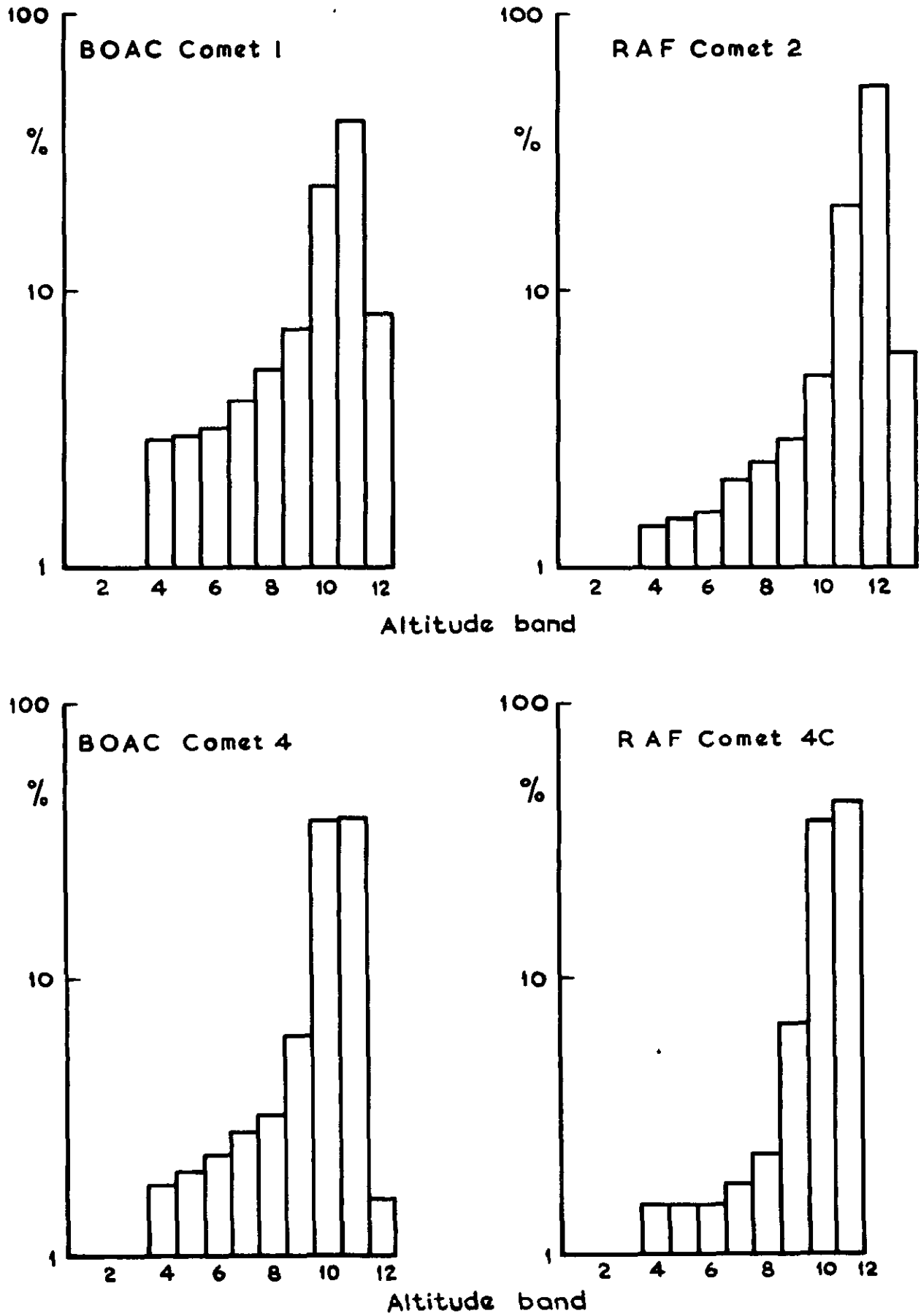

Fig.1 Distance flown in each altitude band, as a percentage of the total distance, (climb, cruise and descent)

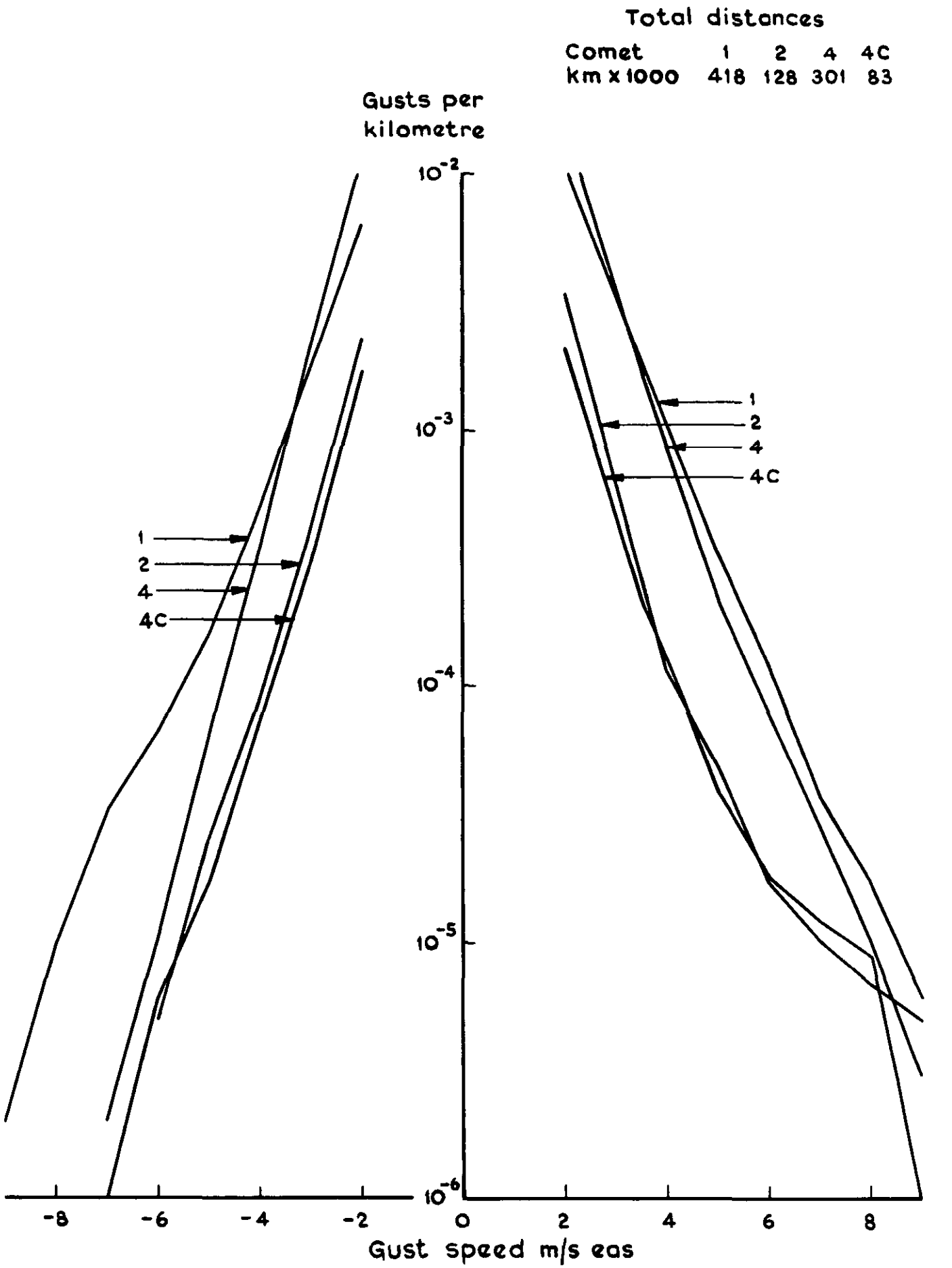

Fig.2 Gusts encountered by each Comet fleet during climb and descent at all altitudes. Discrete gust response factors

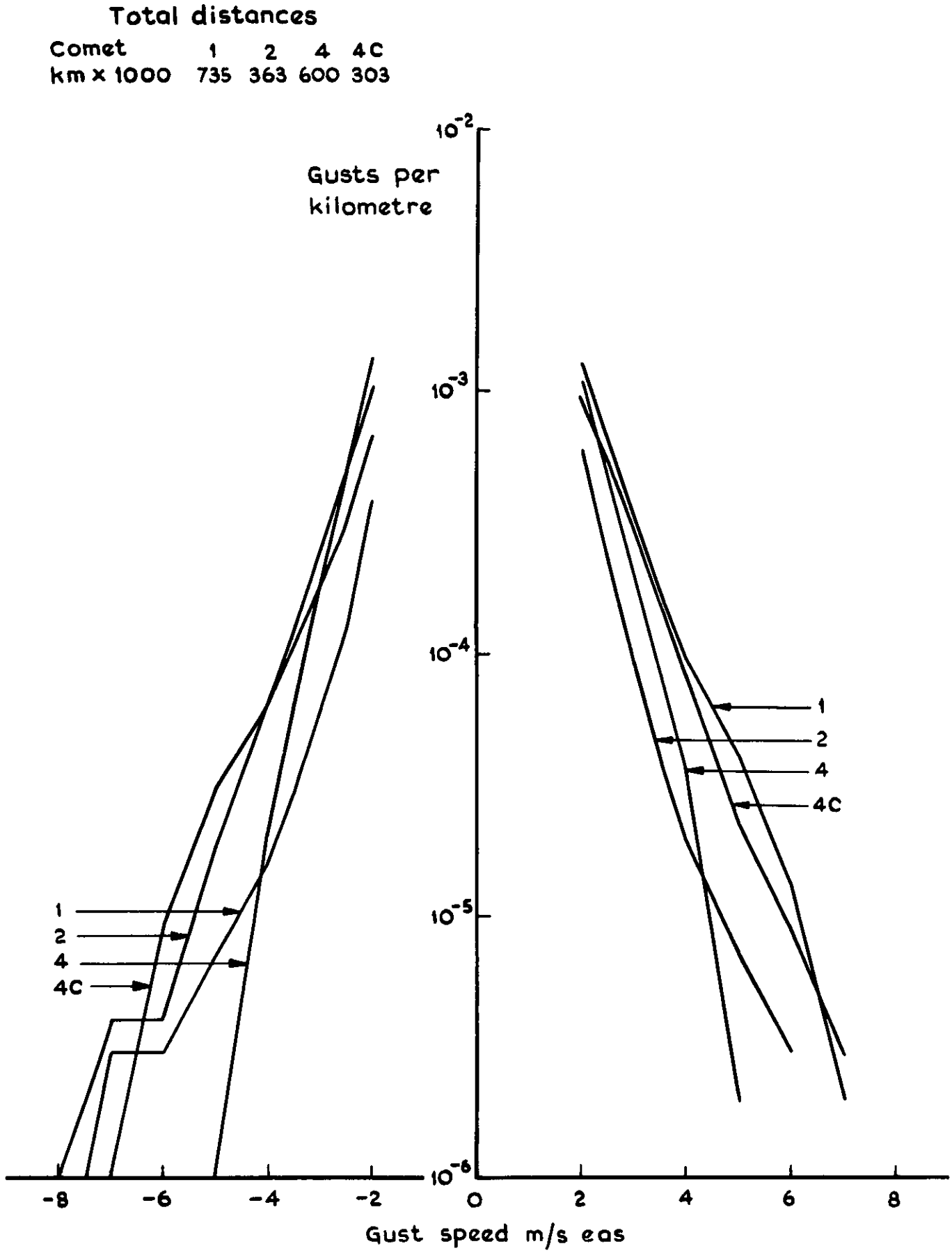

Fig.3 Gusts encountered by each Comet fleet during cruise at all altitudes. Discrete gust response factors

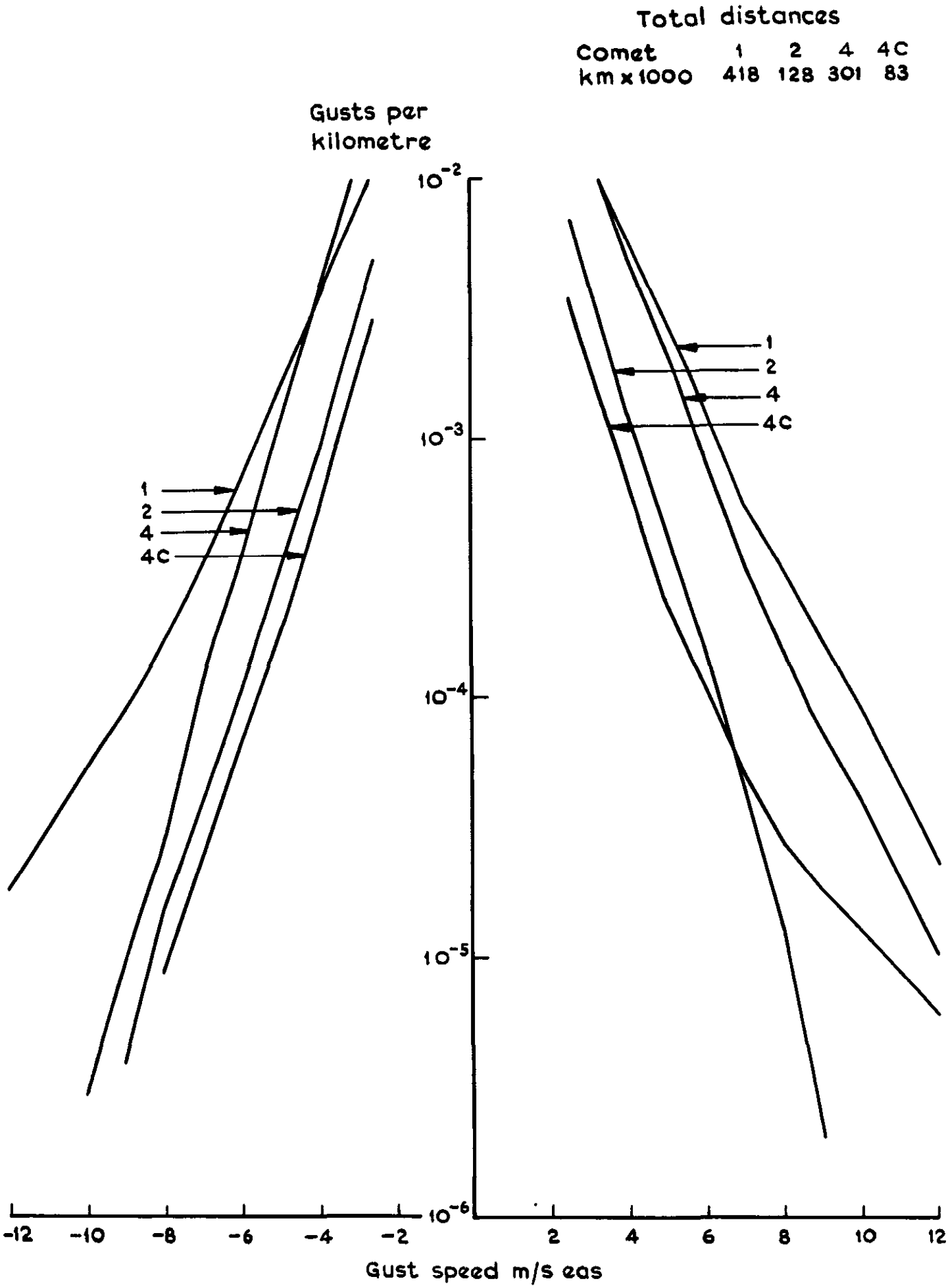

Fig.4 Gusts encountered by each Comet fleet during climb and descent at all altitudes. Spectral gust response factors

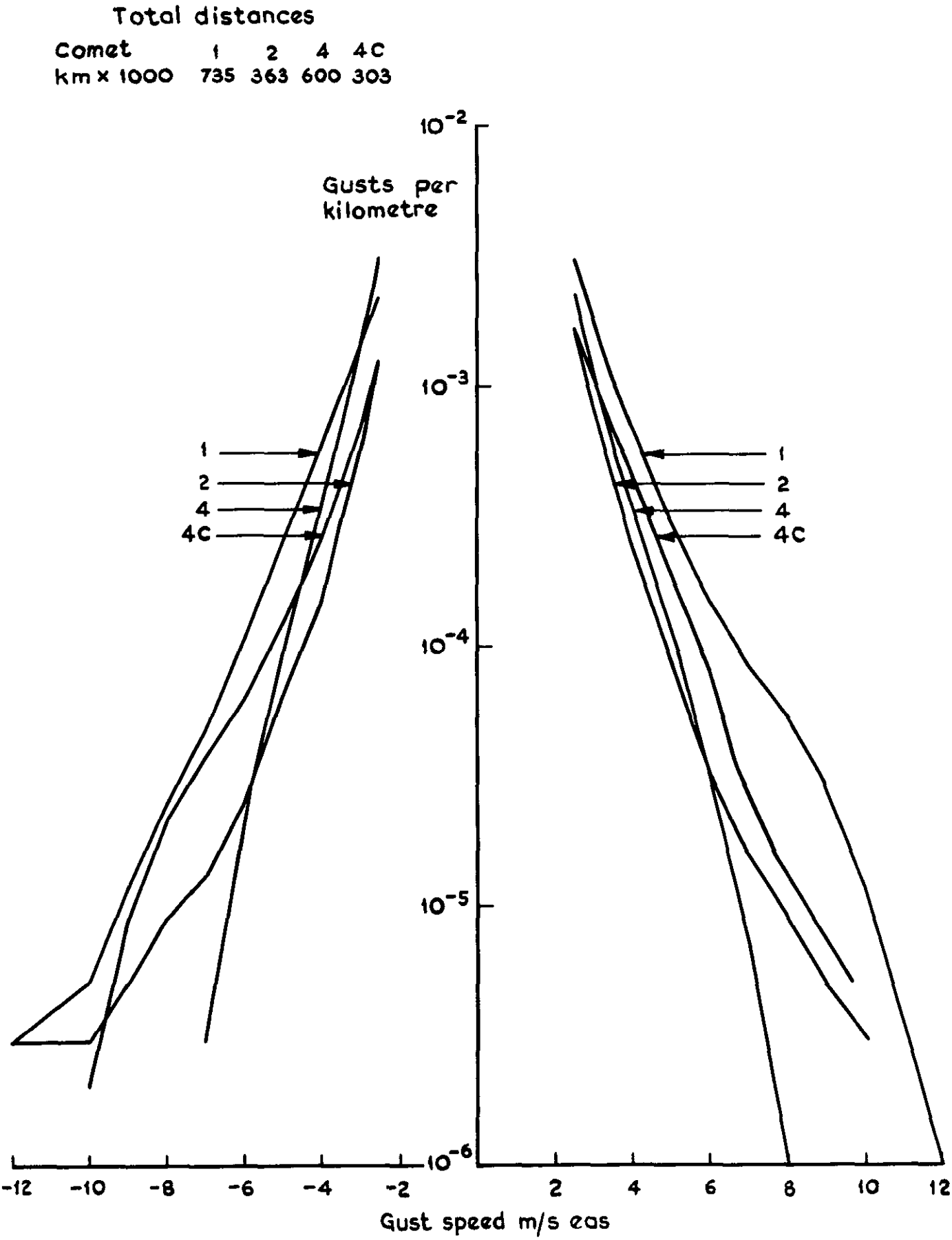

Fig.5 Gusts encountered by each Comet fleet during cruise at all altitudes. Spectrol gust response factors

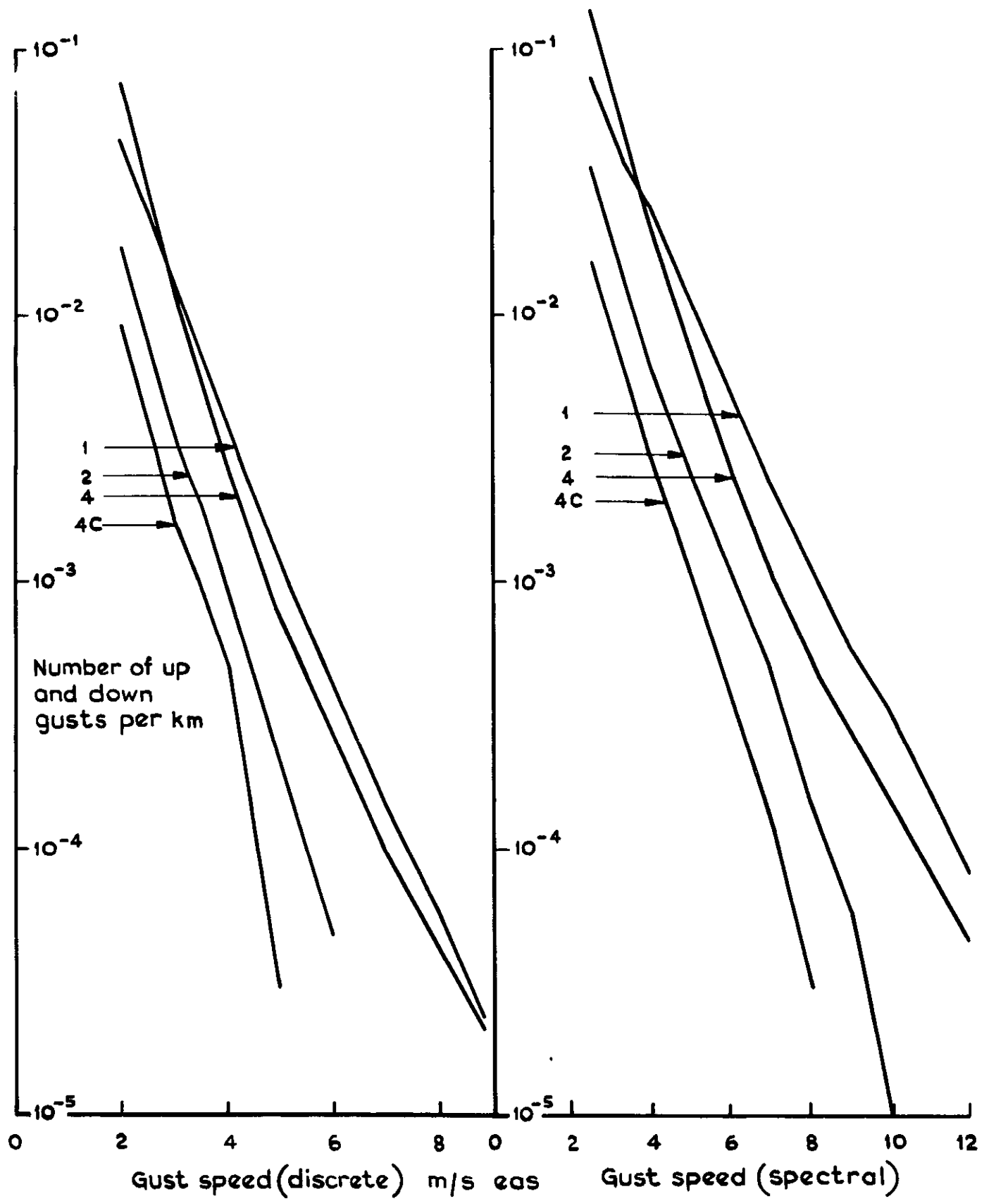

Fig. 6 Gusts encountered by each Comet fleet during climb and descent between 5750 ft and 17750 ft

Total distances				
Comet	1	2	4	4C
km x 1000	186	36	105	29

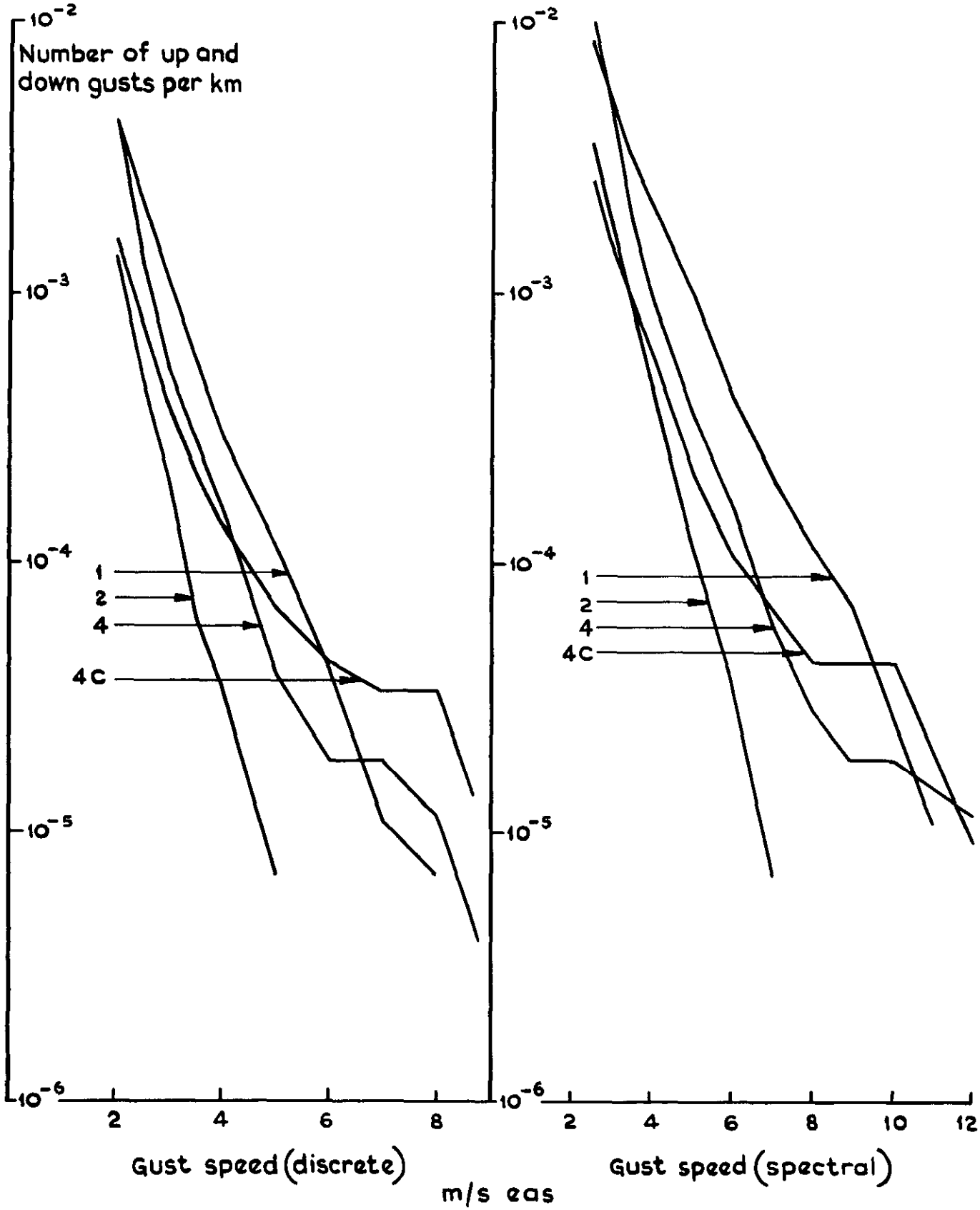

Fig. 7 Gusts encountered by each Comet fleet during climb and descent between 17750 ft and 29750 ft

Total distances

Comet	1	2	4	4C
km x 1000	730	360	591	286

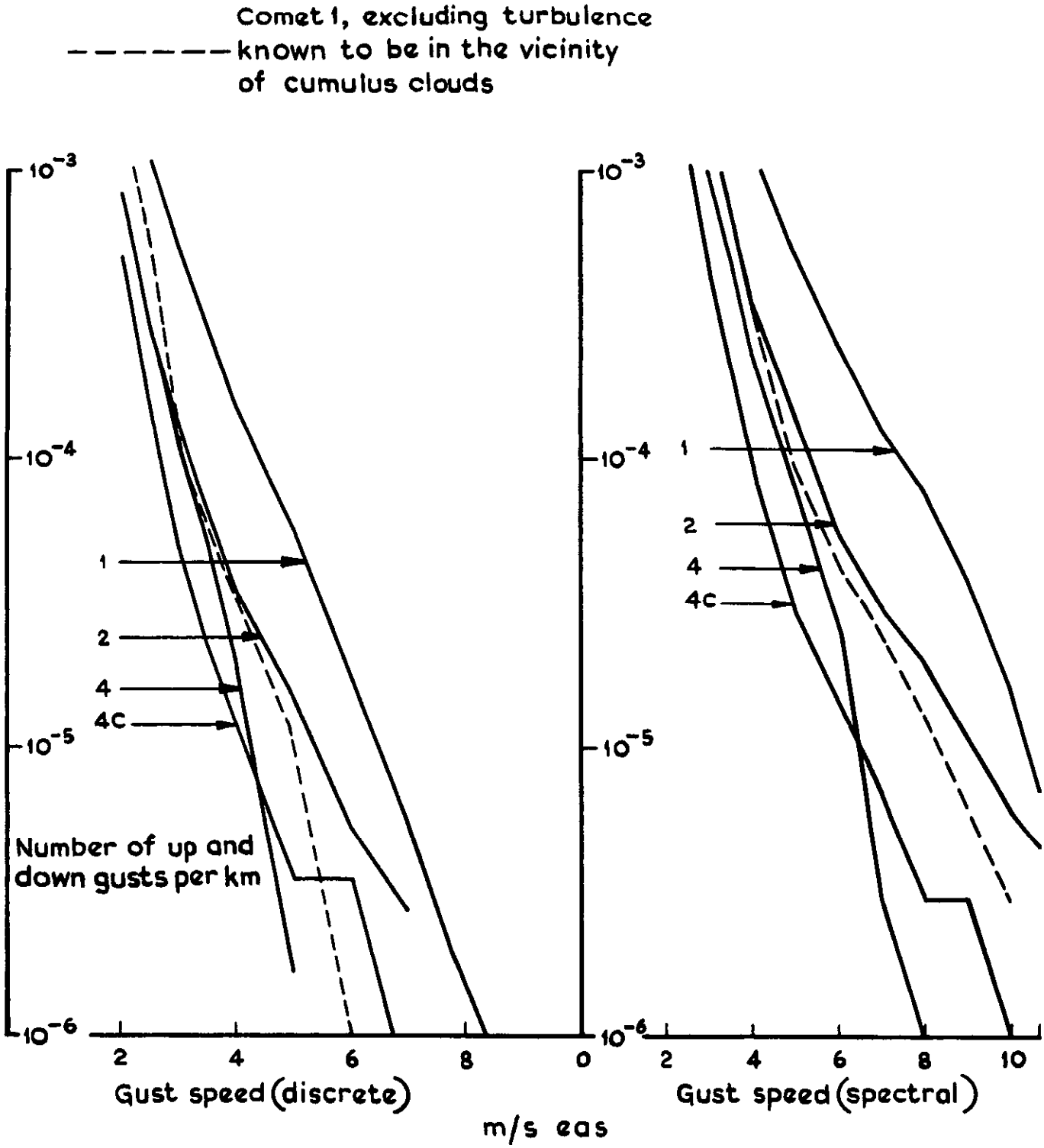

Fig.8 Gusts encountered by each Comet fleet during cruise above 29750 ft

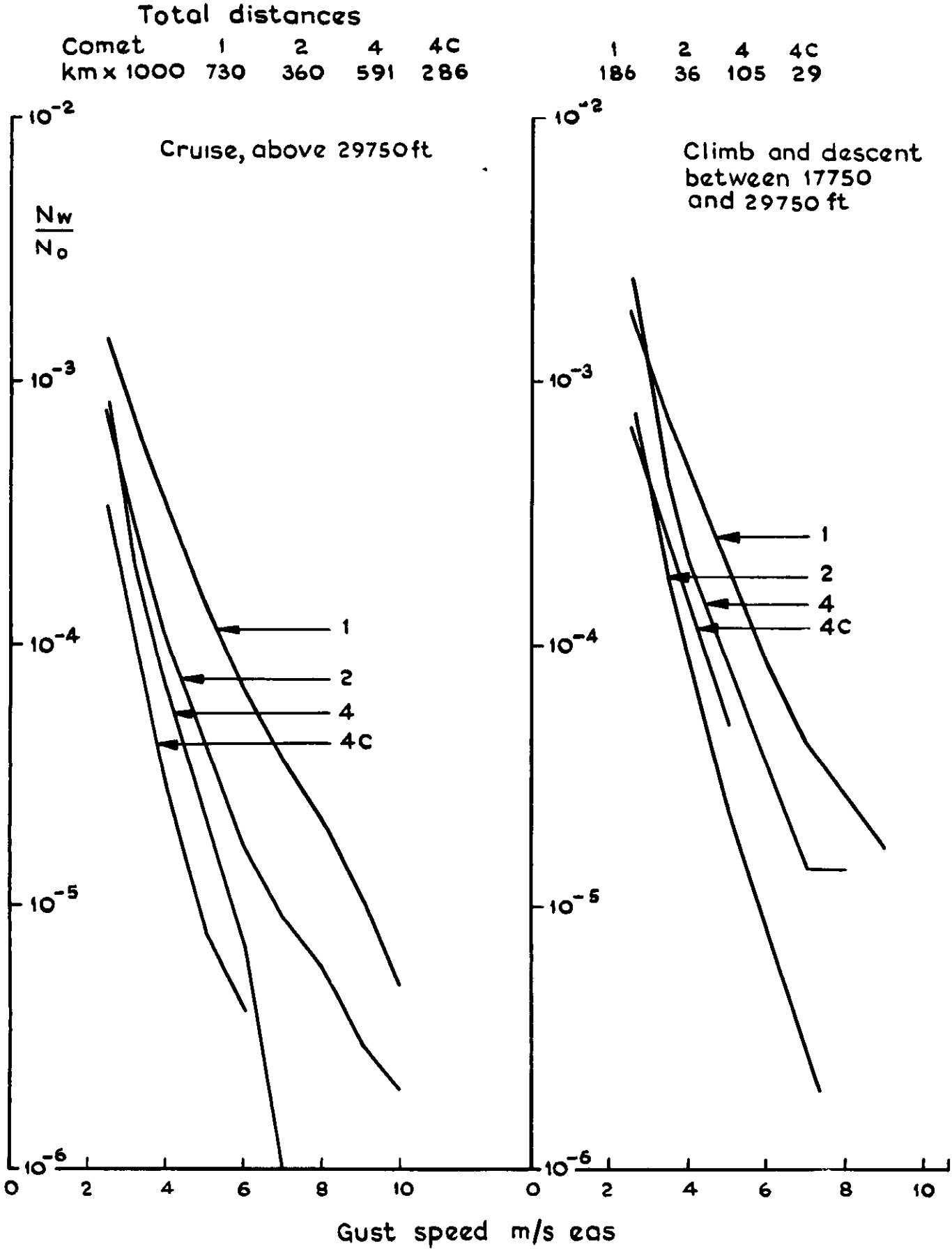

Fig.9 Normalised number of gusts encountered by each Comet fleet, calculated by Kaynes' response factors.

N_w = number of up and down gusts exceeding speed w, per km

N_o = calculated number of zero crossings in continuous turbulence, per km

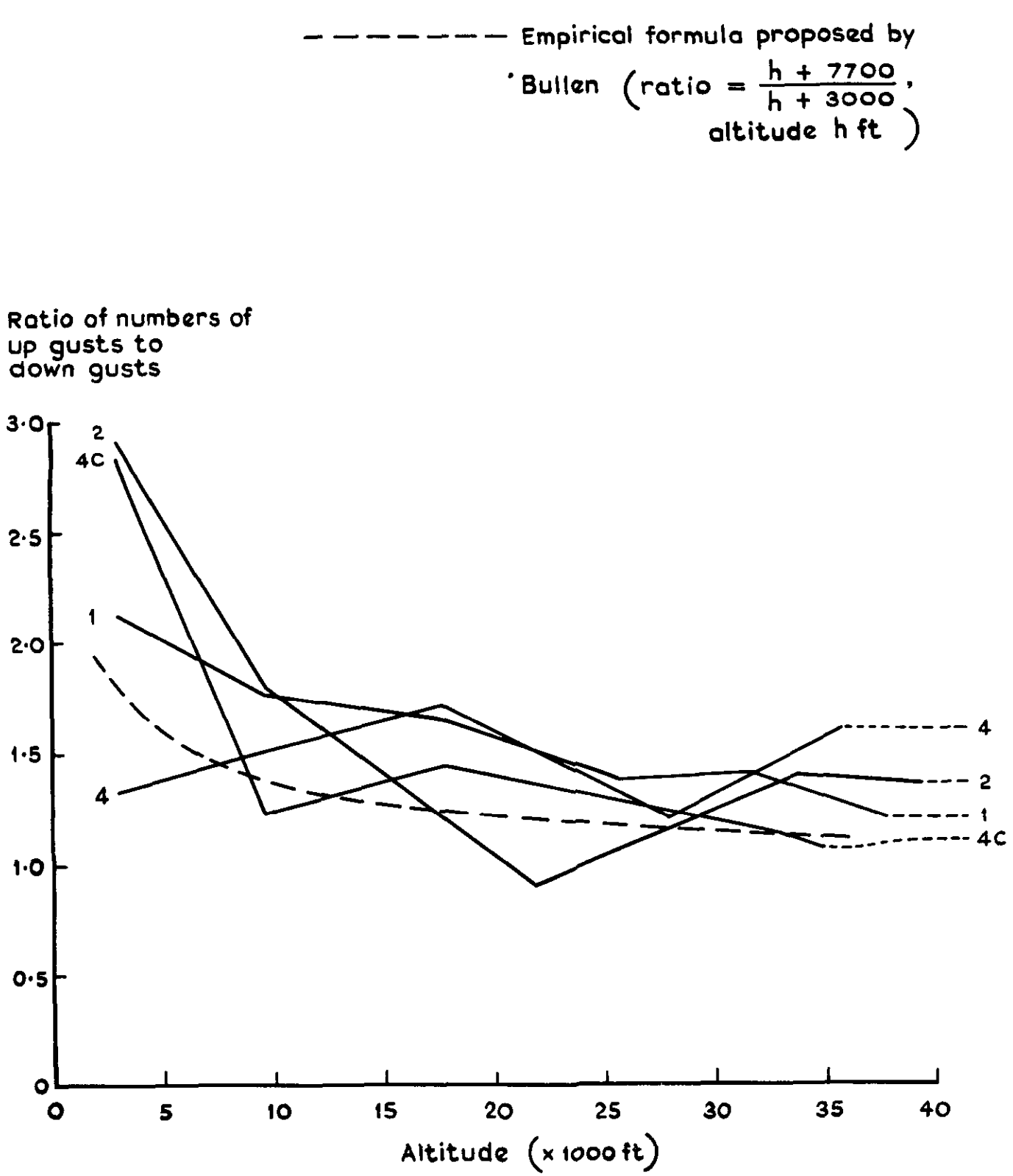

Fig.10 Altitude variations of the ratio of up to down gusts of speeds greater than 4 m/s, by spectral response factors

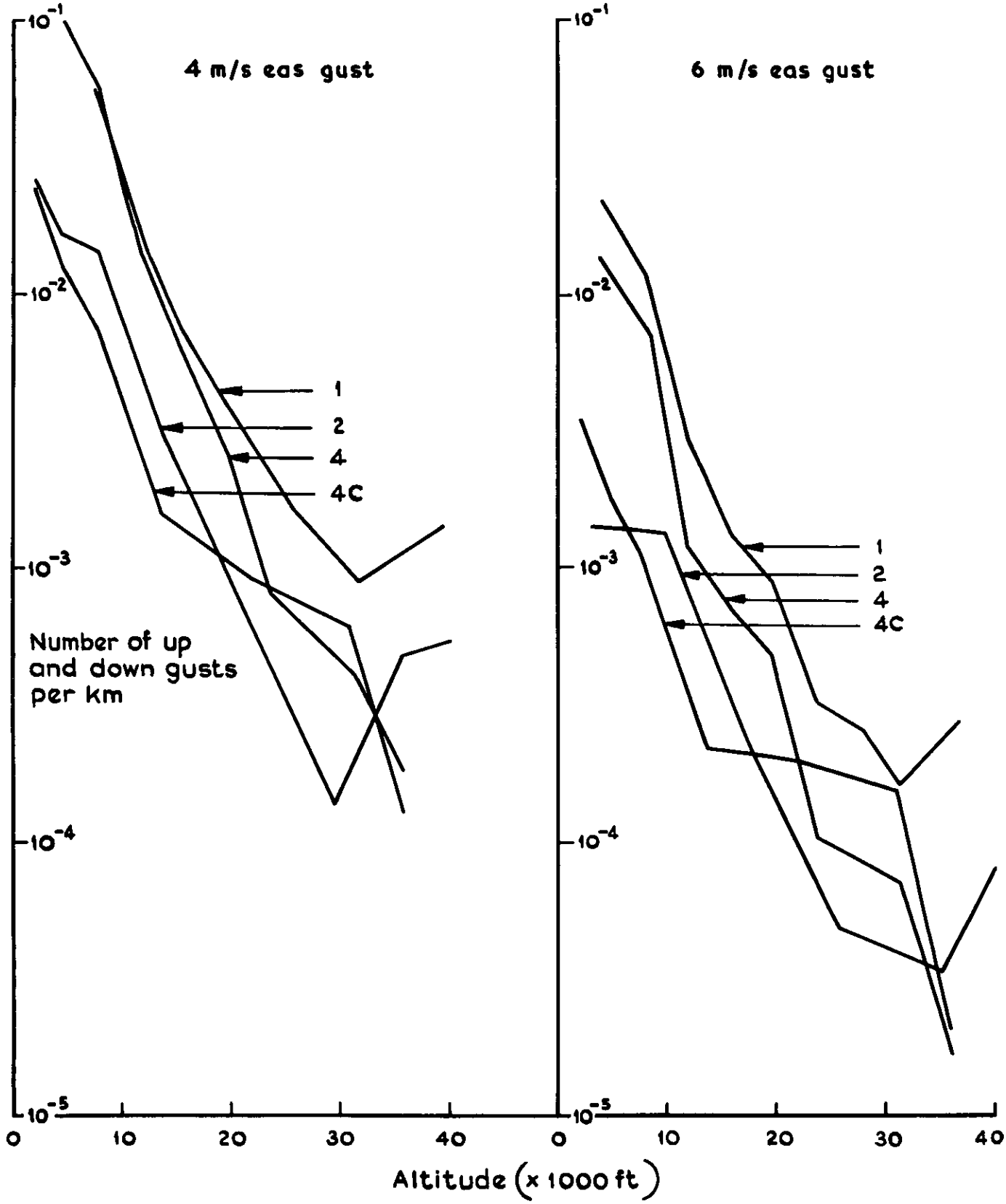

Fig.11 Variation with altitude of the frequency of gusts, calculated with spectral response factors

Total distances (km x 1000)

	G-ALYS	G-ALYX	G-ALYW	G-APDA	G-APDB
Cruise	450	187	87	347	245
Climb and descent	189	70	32	98	62

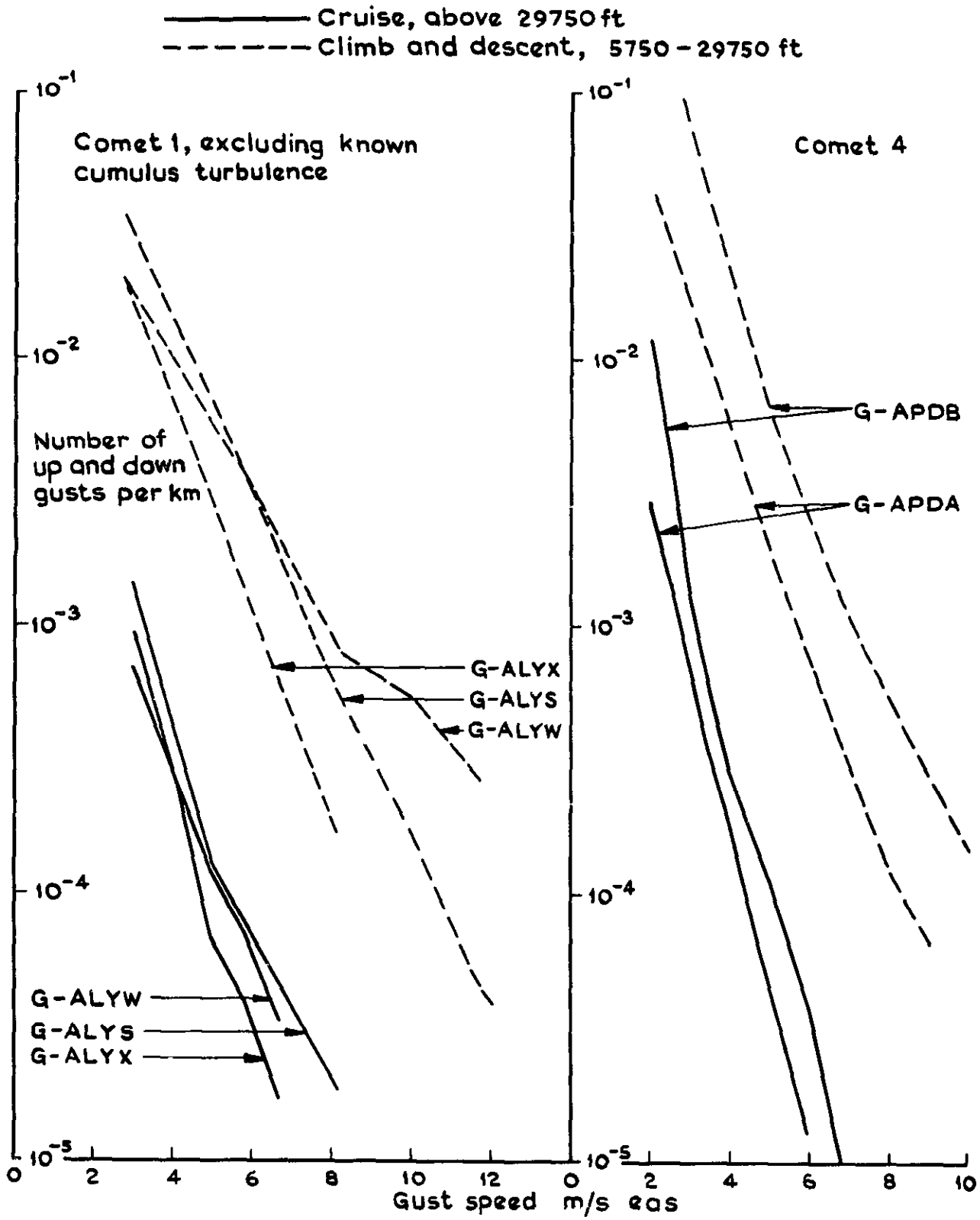

Fig.12 Gusts recorded on individual aircraft
spectral gust response factor

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GUST LOADS ON COMET AIRCRAFT

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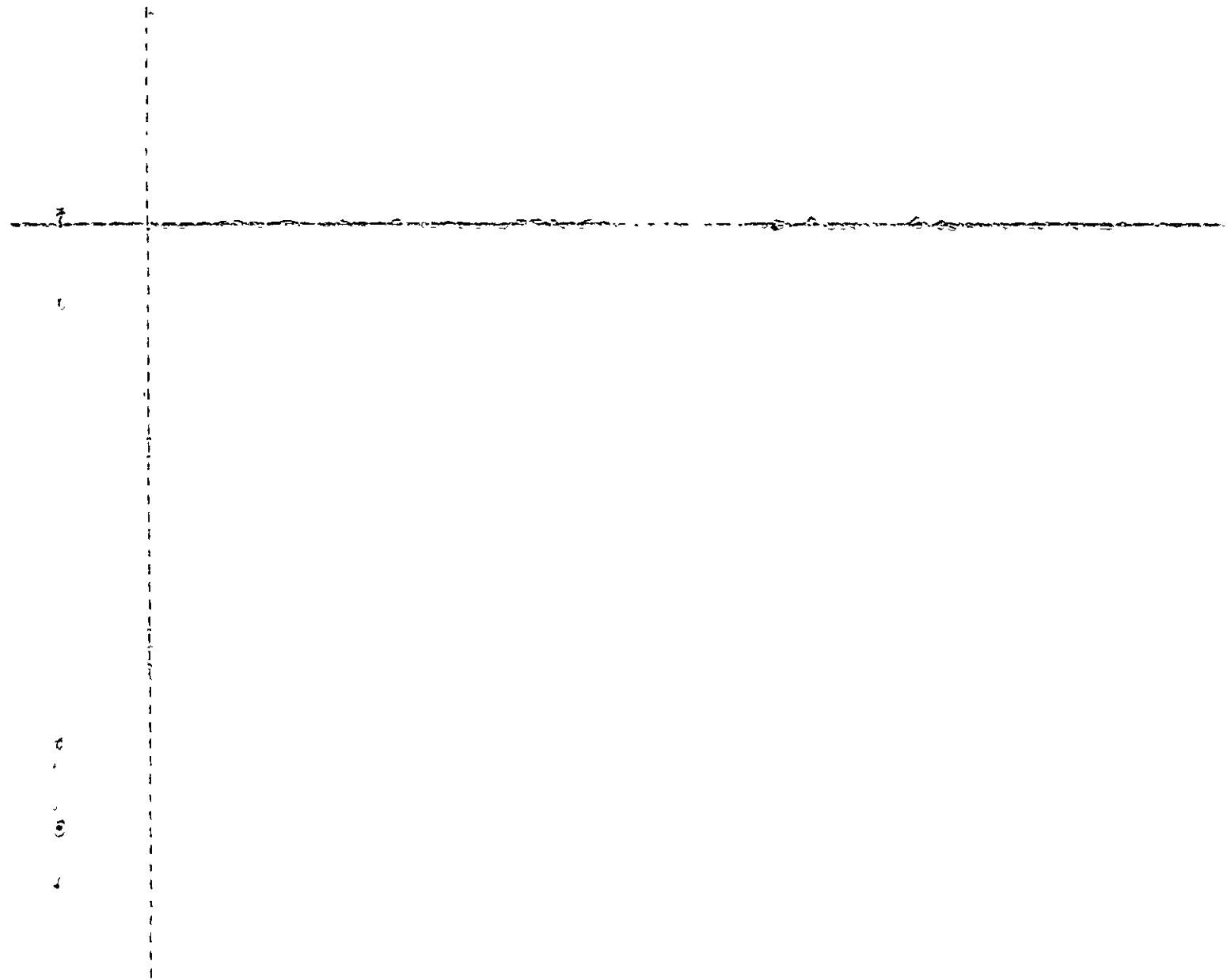

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