C.P. No. 1281

C.P. No. 1281

PROCUREMENT EXECUTIVE, MINISTRY OF DEFENCE

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

Gust Loads on 707 and VC 10 Aircraft

by

I. W. Kaynes
Structures Dept., R.A.E., Farnborough

LONDON: HER MAJESTY'S STATIONERY OFFICE

1974

PRICE *60p* NET

UDC 533.6.048.5

* CP No.1281
August 1972

GUST LOADS ON 707 AND VC 10 AIRCRAFT

by

I. W. Kaynes

SUMMARY

Counting accelerometers have been used to record the centre of gravity normal accelerations on 707 and VC 10 aircraft during passenger services covering 1 870 000 km and 1 700 000 km respectively. A significant difference is found between the frequency of loads on two nominally identical 707 aircraft and the relationship of this to differences in autopilot characteristics is discussed. The most severe loads encountered by each aircraft are described.

---

* Replaces RAE Technical Report 72156 - ARC 34510

CONTENTS

	Page
1 INTRODUCTION	3
2 INSTRUMENTATION	3
3 DATA PROCESSING	3
4 DISCUSSION OF RESULTS	4
4.1 Gust frequency observations	4
4.2 Variations between individual aircraft	7
4.3 Severe loads	8
5 CONCLUSIONS	9
Acknowledgment	9
Tables - 1-5	10-14
References	15
Computer tables - Sheets 1-6	-
Illustrations	Figures 1-10
Detachable abstract cards	-

1 INTRODUCTION

Counting accelerometers have been installed in many transport aircraft in a long term exercise to amass data on centre of gravity normal accelerations, with particular reference to atmospheric turbulence. The Comet has previously been the only jet aircraft studied[1] and to extend the data in areas relevant to modern aircraft this paper describes the loads recorded on 707 and Super VC 10 aircraft operated by BOAC. These represent 2200 flying hours on the 707, that is a distance of 1 870 000 km, and 2000 hours on the VC 10 (1 700 000 km). Two aircraft of each type contributed to the data and notable differences have been found between them.

2 INSTRUMENTATION

The compound counting accelerometer[2,3] Mk.6 was fitted to the aircraft. The accelerometer was rigidly attached to a point near the aircraft centre of gravity and it electrically operated the counters in the observer unit whenever the normal acceleration had exceeded some given upward or downward level and returned to a preset lower value. The observer unit was fitted in a luggage compartment and contained the counters, an altimeter, airspeed indicator and clocks, which were all photographed at intervals of about ten minutes during cruise and five minutes at lower altitudes. An airspeed sensor activated the instrument when the airspeed increased above 125 kn eas and switched off when it fell below 140 kn eas, in order to avoid recording ground loads.

3 DATA PROCESSING

The photographic records were read, punched on to cards and transferred to magnetic tape. Two methods have been used to convert the accelerations to the gust speeds that would have produced them if all the loads had been the result of atmospheric turbulence. One procedure is that of Zbrozek[4] using a discrete gust model, and the other is the author's spectral method for continuous turbulence[5]. The discrete gust is ramp shaped, that is, the vertical velocity of the gust increases linearly from zero to a maximum in a constant gradient distance; assuming a basic value of 30 m for a straight wing aircraft and applying the correction for the sweep of the 707 and VC 10 gives 45 m as the effective gradient length for these aircraft. The two-dimensional Von Karman spectrum of turbulence energy is the input to the spectral model, with a scale length equal to the inverse density ratio times 1000 ft for altitudes greater than 1000 ft, and equal to the altitude for flight lower than this limit.

To calculate aircraft response to both forms of turbulence it is assumed that the aircraft is rigid and does not pitch, which introduces greater errors on the 707 and VC 10 than those on the smaller aircraft previously used for counting accelerometer recording. Extra degrees of freedom could only be incorporated approximately in the equations of motion, for the observations do not cover pertinent factors such as fuel and payload distribution and aircraft configuration. A more complex description of the aircraft dynamics is thus not considered appropriate since it would also be subject to inaccuracies resulting from the assumption about the gust input and the use of response factors.

The data processing sequence is described in more detail in the report summarising counting accelerometer data[6].

4 DISCUSSION OF RESULTS

4.1 Gust frequency observations

During analysis the records were grouped according to altitude bands, defined in Table 1, and flight conditions; apart from the first interval after take off and the last interval before landing, 'climb' and 'descent' described those intervals during which the altitude had changed by 2000 ft or more and 'cruise' applied to the remaining records.

A general impression of the operations flown by these aircraft may be obtained from the histograms of altitude distribution of records, Fig.1, and the distance and number of flights in each of nine geographical regions, Table 2. Both types have nearly identical proportions of flying at different altitudes in climb, cruise and descent, as would be expected from the similar performance, services and operational constraints. The Super VC 10 route pattern was basically transatlantic with comparatively short connecting flights in Europe and North America, including short hops in the West Indies and extensions to South America, while the 707s flew on a more wide ranging pattern around the world.

Table 3 gives the mean values of altitude, speed and mass parameter for sample altitude bands and various stages of flight. The gust response quantities in the table have been calculated for these mean conditions using the methods outlined in the previous section. The gust speeds quoted are employed in predicting loads on different aircraft; the accelerations recorded on one aircraft are converted to equivalent gusts with the appropriate response factor and the loads on another aircraft can then be predicted by translating these gusts into loads for that case. This 'equivalent gust' procedure forms a closed system and it is not necessary either to compare the calculated gusts with actual gusts in the meteorological sense or to compare the equivalent gust speeds predicted by the two methods. Indeed, the discrete and spectral gust models have different physical interpretations; the former predicts the gust speed of an isolated gust that would cause a peak acceleration of 1 g and the latter yields a root mean square gust speed that would correspond to an acceleration response of 1 g rms. The value of gust speed given by the spectral method is larger than the corresponding value for a discrete gust, typically by a margin of one third but this increases to two fifths for descent conditions (with lower mass parameters). The ratio between the response values was a little larger for Comet aircraft[1]. No attempt has been made to allow for structural flexibility. Taylor[7] reduces the gust speed from the spectral calculation by an empirical factor of 1.2. The last column of Table 3 gives the predicted number of times that the acceleration response crosses the undisturbed value under the quoted conditions in continuous turbulence[5].

Computer output tables give the centre of gravity normal accelerations recorded on each fleet together with the numbers of gusts exceeding tabulated speeds. The lowest gust speeds were chosen such that, during cruise, they correspond to an acceleration greater than the lowest level recorded by the accelerometer. In this way, the numbers of gusts at high altitude have been calculated without recourse to extrapolation. This does not apply for altitudes below 10000 ft and so the numbers of the lowest gusts in the first four bands should be treated with caution. The results from the interpolations in each interval have been accumulated as calculated and rounded only just before printing and thus the total numbers for all altitudes are not identically equal to the sum of the corresponding tabulated numbers in each altitude band.

The spatial frequency of gusts at all altitudes is plotted against the gust velocity calculated by both procedures for the 707 and VC 10 fleets in Figs.2 to 5. In all gust frequency plots a negative value of velocity denotes a downward gust. The frequency distributions have been plotted at the values of gust speeds used in the computer tables and connected by straight lines between them. Any gust speeds could have been selected but these define the line accurately at lower magnitudes while for higher gust speeds a closer spacing would not have been appropriate for the smaller number of gusts.

The wide scope of the data covered by each curve precludes any significant conclusions but it is apparent that the VC 10 has a greater ratio of upward to downward loads than either the 707 or the earlier aircraft that have carried counting accelerometers[6].

To investigate this anomaly further the records have been subdivided according to individual aircraft and altitude band categories. Fig.6 shows the variation with altitude of the ratio of upward to downward accelerations at the 0.2 g increment level. This particular load was chosen in order to give the largest number of occurrences and thus the greatest statistical significance, while accelerations were preferred to gusts because a gust speed that is sufficiently high to avoid extrapolation uncertainties at low altitude has been observed infrequently at high altitude. Earlier records[6] have shown the ratio of upward to downward loads to be greater than unity and to decrease towards this value with increasing altitude. The two 707 aircraft do not greatly depart from this pattern, excepting that the ratio is rather lower than normal on one aircraft and for the other aircraft it does not increase for records below 10000 ft. The VC 10 aircraft D follows the established altitude trend with a marked bias towards upward loads at low level, whereas the curve for aircraft C shown an upward shift at all altitudes. The latter curve tends to a ratio of 2.2 more upward than downward accelerations in the manner that has normally been seen approaching a limit of just over one. The gradient of the acceleration frequency distribution curve (Fig.7) is such that this corresponds to an acceleration datum shift of 0.02 g. The possibility of an inaccuracy of this order had been noted during recording but was not investigated further when the accelerometer was removed from the aircraft. The effect of this datum shift on some forms of analysis can be reduced by adding the up and down loads where appropriate. Averaging in this way gives a load frequency rather higher than would have resulted if a datum shift had been assumed and allowed for precisely*. This difference can hardly be detected on the frequency distribution curves.

---

* Assume that the numbers of accelerations measured at some level were n down and 2.2n up and the logarithmic frequency distribution is a linear function of acceleration with a gradient typical of the lines in Fig.7. Moving the origin sufficiently to give a ratio of up loads to down loads of 1.1 (that is $n\sqrt{2}$ down and $1.1\sqrt{2}n$ up) would give respective totals of loads in both directions of 3.2n and $2.1\sqrt{2}n$, a difference of 7.7%.

4.2 Variations between individual aircraft

Before comparing the loads recorded on each aircraft the data should be examined for any bias that may exist. The VC 10s are found to have flown a very similar global pattern (Table 2) but the recordings on one aircraft were concentrated between April and July while the other had a minimum of data from this period and most between September and February (Fig.1b). Past studies, such as Ref.8, have confirmed that gust loads vary with season and, since almost all flying was in the northern hemisphere, this reduces the validity of comparisons between the two VC 10 aircraft. On the other hand, the 707 records have more similar seasonal and geographical distributions and so these aircraft can be compared with greater significance. Data from aircraft B are about two and a half times more extensive than those from aircraft A and thus the corresponding load frequency estimates have less scatter.

Subject to these remarks on significance, Figs.8 and 9 compare the gusts encountered by the individual aircraft of each fleet for major subdivisions of their flight profiles. In each case the subdivisions represent very similar proportions of the total distances, these being 2% for the low altitude records, 5% and 8% in the intermediate stages of climb and descent and 70% for the high altitude cruise. These major flight conditions do not show one VC 10 to have consistently recorded loads more frequently than the other. This is reinforced by the altitude variation of the frequency of 4 m/s gusts (Fig.10), the two curves crossing and re-crossing below 30000 ft. Most of the severe loads on VC 10s were recorded on aircraft D and it is found that just two data intervals at 34000 ft and four within the 5750 to 17750 ft subdivision account for all but 10% of the difference between the respective gust frequency distribution curves. Since the number of severe observations is so small it cannot be inferred that there is a significant variation between the characteristics of these aircraft.

The 707 records from aircraft A show loads more frequent than those on aircraft B for most magnitudes in all stages of flight. At low altitude the difference is not very large but the altitude variation curves show a sudden separation at 20000 ft and thereafter frequencies differ by up to four times. This quite significant difference is greater than would be expected for two aircraft of the same type flying on the same operations, since this high altitude flying represents a large proportion of the recorded data.

The aircraft were fitted with analogue trace recorders for the Civil Aircraft Airworthiness Data Recording Programme and yielded part of the 23000 hours of operational flying studied by King[9]. Two forms of pitch oscillation related to the autopilot were found[10]. One occurred during cruise with the height lock mode engaged and was of low frequency and long duration. This would seldom cause loads large enough to be recorded by the counting accelerometer during cruise in smooth air but it would amplify response to light turbulence and so increase the counting rate at the lowest acceleration levels. The other form of hunting was a higher frequency pitch oscillation, within the range 0.1 to 0.5 Hz, which was associated with the pitch attitude control function of the autopilot. It commonly developed at the end of climb or start of descent, that is, at the time of engagement and disengagement of the height lock mode, and sometimes persisted for several minutes. These characteristics were extremely pronounced on aircraft A and could explain the higher frequency of loads of low magnitude. Fig.8 shows this as a consistently higher frequency of apparent gusts with speeds less than 5 m/s eas. The small number of severe turbulence patches means that the inconsistency for gust speeds above this value is not statistically significant.

When discussing the differences between these aircraft, Sturgeon[11] has suggested that the autopilot induced amplification of mild turbulence loads would not necessarily imply an increase in severe loads but could represent a significant commercial penalty in fatigue life. Severe turbulence may have been encountered with the autopilot in any mode[9] and so the design should have good turbulence response characteristics in all modes. From the few severe loads recorded by the counting accelerometers it is not possible to make any inference as to the relative behaviour of these aircraft in such circumstances.

4.3 Severe loads

Some individual records of severe loads are given in Tables 4 and 5. These have been chosen according to the three stated criteria, which were defined to give a small number of the most severe loads observed. From a selection of this size no conclusions can be drawn as regards the distribution of loads between each aircraft, season and location but it forms a typical sample of the general flying of the observed fleets.

Further details of some of the 707 events have been obtained from crew reports and CAADRP records. Patch 2 of Table 4 was noted by the crew as severe turbulence for the forty minutes covered by these three intervals, but it is possible that oscillations induced by the autopilot were tending to amplify the response. Examination of the 0.2g loads reveals that they could have resulted from an oscillation of 0.2g amplitude with a period of about one half minute, representing altitude variations of 150 ft about the mean. The report on event 7 describes moderate turbulence of a similar duration but in this case adjacent intervals record only a few accelerations and these are at the lowest magnitude recorded by the accelerometer. Event 9 is the subject of section 4.3.6 of Ref.12 in which it is noted that, while the autopilot instability in height lock mode may have increased loads, it was an exceptionally short and intense patch of turbulence. The flight crew's description of event 11 records entering turbulence at 34000 ft and severe turbulence for three or four seconds, during which time the recorded air temperature rose from -54°C to -48°C.

5 CONCLUSIONS

Analysis of counting accelerometer data recorded on long range transport aircraft in passenger service has indicated the frequency of loads to be expected for such operations.

Two nominally identical aircraft from one fleet encountered loads at frequencies differing by up to four times. Studies of analogue trace records from these aircraft show that autopilot induced oscillations are much more severe on one aircraft and could completely explain the discrepancy in load frequencies at the fatigue level at high altitude.

Details have been given for selected severe loads recorded by the accelerometer, including five events at high altitude for the 707 and two such events for the VC 10.

Acknowledgment

Thanks are due to the British Overseas Airways Corporation for their assistance in collecting the data.

Table 1

KEY TO 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 2

GEOGRAPHICAL DISTRIBUTION OF FLYING RECORDED ON EACH AIRCRAFT

Flying distance (km) is followed by the number of flights recorded

Zone	707		VC 10	
	A	B	C	D
Europe	37935, 27	66644, 70	52441, 41	18684, 7
Indian Ocean	6174, 2	43798, 11	-	-
Africa	-	-	18269, 4	967, 1
Middle and Far East	114412, 43	219275, 72	16539, 9	-
Australasia	23649, 6	42864, 13	-	-
North Atlantic	223646, 52	771606, 188	767391, 173	640906, 185
Pacific	64437, 13	101839, 20	-	-
North America	51574, 34	82554, 69	56710, 60	52136, 71
South America	6758, 2	7001, 6	30307, 10	45010, 14

Table 3

MEAN CONDITIONS AT TYPICAL STAGES OF FLIGHT

Aircraft	Flight condition	Altitude band	Mean values			Response parameters corresponding to mean conditions		
			Altitude ft	Speed kn eas	Mass parameter	F (discrete)	F (spectral)	Zero crossings, per km
707	climb	3	4900	255	31.8	15.3	20.3	4.51
	climb	5	11800	282	36.7	12.8	17.1	3.98
	climb	8	23750	289	51.9	11.7	15.6	3.05
	cruise	10 and 11	34000	283	61.0	10.1	13.4	2.35
	descent	8	23750	293	40.7	9.3	13.0	3.23
	descent	5	11750	273	29.0	10.6	14.8	4.28
	descent	3	4720	222	22.6	13.2	18.4	5.09
VC 10	climb	3	4940	252	31.9	15.3	20.4	4.52
	climb	5	11730	281	36.2	12.5	16.9	4.01
	climb	8	23800	289	56.3	12.4	16.4	2.99
	cruise	10 and 11	33800	286	75.4	12.1	15.5	2.21
	descent	8	23780	292	42.0	9.5	13.2	3.22
	descent	5	11800	272	30.0	10.9	15.2	4.27
	descent	3	4720	223	23.9	13.5	18.8	5.01

F represents the gust speed (m/s eas) predicted to produce a 1g load

Table 4 - THE MOST SEVERE LOADS RECORDED ON 707 AIRCRAFT ABOVE 5750 ft

Aircraft		Month	Route	Stage of flight	EAS km	Altitude ft	Interval min	Selection criteria	F	Acceleration increments, g										
										Down						Up				
										1.0	0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8
1	B	April	London to Montreal	descent	225	7000	5	B,C	18.5			1	1	1	4	6	2	1		
2	A	May	Tokyo to Honolulu	cruise, 5 h after take off	285	32500	12 each	A,C	13.3			1	4	8	22	25	6	2		
													2	7	26	35	6	1		
														6	23	27	3	1		
3	B	June	London to New York	descent	255	9500	5	C	14.4			1	1	1	5	3	1			
4	B	June	Toronto to Montreal	climb	265	13000	5	C	14.8				3	4	5	7	5	3	1	
5	A	July	Manilla to Sydney	commencing cruise	275	33000	13	A	15.7				7	14	21	11	6	1		
6	B	Sept.	Kingston to Montego Bay	cruise, on short flight	300	10000	3	C	13.2			1	2	6	18	4				
7	B	April	Boston to London	cruise 1 h after take off	300	30000	15	C	13.8				1	1	1	5	3	1	1	
8	A	July	Zurich to Tel Aviv	climb	235	6000	3	A	21.3					3	4	10	3			
9	A	July	Bangkok to Hong Kong	cruise	285	35000	12	B,C	12.8	1	1	1	2	2	5	6	3	1		
10	B	Sept.	Montreal to London	descent	235	6500	5	A	17.9				1	1	2	8	6	4		
11	B	Nov.	Frankfurt to Tehran	descent	270	29000	7	A, B, C	14.2		2	3	6	9	16	16	9	5	2	1

Selection criteria satisfied by each patch are identified as A: at least 4 gusts exceeding 6 m/s
B: at least 1 gust exceeding 9 m/s
C: at least 1 acceleration increment exceeding 0.6 g

The column headed 'F' gives the gust speed (m/s eas) predicted to produce a 1g load, by the spectral method.

Table 5

THE MOST SEVERE LOADS RECORDED ON VC 10 AIRCRAFT ABOVE 5750 ft

Aircraft	Month	Route	Stage of flight	EAS km	Altitude ft	Interval min	Selection criteria	F	Acceleration increments, g								
									Down					Up			
									0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6
D	Dec.	London to New York	cruise, 2 h after take off	275	34000	11	A	16.7			3	9	36	23	5		
D	Dec.	Montego Bay to Nassau	descent	260	6500	3	A	17.6			2	2	10	12	7	1	
D	Jan.	Kingston to Lima	cruise, 2½ h after take off	270	34000	12	A,B,C	15.3	1	1	2	6	13	14	7	6	2
D	Jan.	Nassau to New York	climb	285	8500	5	A,B,C	16.9	1	1	2	6	18	24	8	3	
D	Feb.	Kingston to Montego Bay	cruise, on short flight	270	8500	5	A	17.3			2	2	7	6	3	1	
D	July	London to New York	climb	245	7500	5	A,B	24.3			1	2	2	3	2		
D	June	Kingston to Montego Bay	climb	255	7000	4	A	18.3			1	3	5	11	7	1	
C	Jan.	Boston to New York	descent	250	19000	5	A	17.8			1	1	3	13	5	1	
C	July	London to New York	climb	295	18000	5	A	19.3			1	3	4	13	2	1	

(Key as for table 4)

REFERENCES

No.	Author	Title, etc.
1	I.W. Kaynes	Gust loads on Comet aircraft. ARC CP No.1247 (1971)
2	J. Taylor	Accelerometers for determining aircraft flight loads. Engineering, 11 and 18 April, 1952, pp. 473-475 and 506-507.
3	J. Taylor	Design and use of counting accelerometers ARC R and M 2812 (1950)
4	J.K. Zbrozek	Gust alleviation factors (Parts I, II and III) ARC R and M 2970 (1953)
5	I.W. Kaynes	Aircraft centre of gravity response to two-dimensional spectra of turbulence ARC R and M 3665 (1969)
6	I.W. Kaynes	A summary of the analysis of gust loads recorded by counting accelerometers on seventeen types of aircraft. RAE Technical Report 72157 (ARC 34517) (1972)
7	J. Taylor	Gust loads for structural design. International conference on atmospheric turbulence RAeS, May 1971
8	R. Hain Taylor	Annual variation of flight loads recorded on Viscount aircraft by means of the fatigue load meter. ARC CP No.667 (1962)
9	G.E. King	Civil Aircraft Airworthiness Data Recording Programmes. Some characteristics of severe turbulence. ARC CP No.1098 (1969)
10	-	Special events relating to autopilot induced control disturbances. CAADRP Technical Report 6 (ARC 29737) (1967)

REFERENCES (concluded)

No.	Author	Title, etc.
11	J.R. Sturgeon	Turbulence experience recorded by CAADRP. International conference on atmospheric turbulence RAeS May, 1971
12		Special events of meteorological origin (January 1965 to December 1965). CAADRP Technical Report 4, RAE Technical Report 67071 (ARC 29659) (1967)

Table.1

C.T. 1

ACCELERATIONS RECORDED ON THE 707

NUMBER OF TIMES THAT EACH ACCELERATION LEVEL (G) WAS EXCEEDED

ALT BAND	DISTANCE KM	TIME MIN	DOWNWARD						UPWARD					
			1.0	0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
TAKE OFF														
ALL	16390	2456			2	6	53	448	414	59	1			
LANDING														
ALL	7573	1522				5	21	97	83	16	5			
CLIMB														
2	1501	195					2	14	11	4	1			
3	3626	431				1	8	63	42	4	2			
4	14786	1584				1	17	142	135	22	7			
5	15825	1523				8	19	92	80	17	6	1		
6	17272	1533					3	38	30	5				
7	19767	1640					5	38	28	2				
8	24382	1874					2	24	15	3	1			
9	35069	2500				1	5	54	61	10	3			
10	52606	3547					6	62	40	3	1			
11	26412	1726					1	16	11					
12	2270	146												
ALL	213517	16699				11	68	543	453	70	21	1		
CRUISE														
1	2418	445				1	3	41	60	7	3			
2	6053	1007					3	138	160	22	2			
3	2801	370				1	7	49	61	9	2			
4	1700	198					6	19	16	2	1			
5	2118	234			1	2	6	22	19	3	1			
6	1744	155					1	2	8					
7	8901	705					1	24	13					
8	22351	1566					2	15	11	2				
9	83597	5508					6	60	43	6				
10	425417	27899			1	19	58	341	308	50	9	1		
11	785260	50866	1	1	1	3	34	345	190	26	4			
12	94294	6001					8	74	53	8	1			
ALL	1436655	94954	1	1	3	26	135	1130	942	135	23	1		
DESCENT														
2	4575	744				3	16	139	179	39	5			
3	7077	985				4	19	136	172	38	6			
4	17702	2058			2	10	34	249	304	59	8			
5	16594	1667				2	17	91	154	21	4			
6	17606	1595				1	6	49	74	12	3			
7	17843	1460					10	53	49	10	2			
8	18886	1437					1	23	21	2				
9	29962	2119		2	3	9	25	96	86	27	9	2	1	
10	39273	2677					2	32	26					
11	19251	1260					4	19	12	3	1			
12	1263	80												
ALL	190031	16082		2	5	29	134	887	1077	211	38	2	1	

Table.1 (cont'd.)

C.T. 2

ACCELERATIONS RECORDED ON THE SUPER VC 10

NUMBER OF TIMES THAT EACH ACCELERATION LEVEL (G) WAS EXCEEDED

ALT BAND	DISTANCE KM	TIME MIN	DOWNWARD						UPWARD					
			1.0	0.8	0.6	0.4	0.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
TAKE OFF														
ALL	8202	1329				2	22	173	296	34	5			
LANDING														
ALL	4954	1104				2	18	156	640	226	78			
CLIMB														
2	901	119					1	8	14					
3	2975	358					4	29	53	8	1			
4	13836	1485		1	1	5	20	91	157	44	7			
5	13814	1338				1	9	45	77	16				
6	12524	1110					1	4	9	4	1			
7	19599	1608				1	4	15	37	6	2			
8	19605	1504					4	16	23	5	2			
9	44750	3151					2	9	29	2				
10	54842	3622					2	29	45	7	2			
11	23064	1459					2	7	23	2				
12	2217	135						1	2					
ALL	208127	15889		1	1	7	49	254	469	94	15			
CRUISE														
1	3917	742					3	17	109	13	2			
2	7190	1186					6	56	236	38	4			
3	2711	371					2	29	62	10	3			
4	2506	303				3	3	12	26	6	1			
5	2330	258					1	3	10	2				
6	2085	215							12	3	1			
7	6215	505							2					
8	15724	1206					3	16	33	6	1			
9	67653	4659					2	19	22	2	1			
10	470937	30594				1	15	68	108	12	1			
11	671197	43230		1	1	9	53	277	321	45	13	2		
12	62008	3806						1	6	1				
ALL	1314473	87075		1	1	13	88	498	947	138	27	2		
DESCENT														
1	609	122					2	7	14					
2	6113	1017					3	33	162	30	4			
3	8209	1134					4	26	124	13	3			
4	17502	2042				6	20	90	234	45	7			
5	15331	1540				1	3	28	88	18	2			
6	14991	1370						18	56	9	2			
7	13913	1166				1	4	16	54	12	2			
8	14670	1128						14	26	4	2			
9	33508	2394				1	5	50	70	18	2			
10	29682	2003					3	22	34	6				
11	8733	559					2	8	15	3				
12	343	22												
ALL	163604	14497				9	46	312	877	158	24			

Table.1 (cont'd.)

C.T. 3

GUSTS ENCOUNTERED BY THE 707 , CALCULATED BY THE DISCRETE GUST METHOD

NUMBER OF TIMES THAT EACH GUST SPEED (M/S EAS) WAS EXCEEDED

ALT BAND	DISTANCE KM	TIME MIN	DOWNWARD								UPWARD							
			10	8	7	6	5	4	3	2.5	2.5	3	4	5	6	7	8	10
	TAKE OFF																	
ALL	16390	2456		3	6	18	71	218	576	873	787	523	201	61	16	6	1	
	LANDING																	
ALL	7573	1522		1	2	6	17	47	124	187	165	113	44	13	5	2	1	
	CLIMB																	
2	1501	195				1	2	8	20	29	20	15	8	4	2	1	1	
3	3626	431					2	16	65	105	63	36	10	3	1			
4	14786	1584				1	6	21	91	171	169	93	27	8	1			
5	15825	1523				1	3	12	38	74	61	31	10	3	1			
6	17272	1533							10	26	21	9	1					
7	19767	1640						3	11	23	18	7	2					
8	24382	1874						1	6	15	8	5	3	1	1			
9	35069	2500						2	14	40	49	25	7	2				
10	52606	3547						2	14	36	20	7	2	1				
11	26412	1726							2	7	4	1						
12	2270	146																
ALL	213517	16699			1	3	14	66	271	526	433	228	69	22	6	2	1	
	CRUISE																	
1	2418	445	1	1	2	3	5	16	53	82	124	82	28	8	5	3	2	1
2	6053	1007					3	33	150	255	272	165	47	16	4			
3	2801	370				1	2	6	25	50	69	37	9	2				
4	1700	198						3	10	16	17	8	2	2				
5	2118	234				1	1	2	6	12	14	7	1					
6	1744	155							1	2	5	2						
7	8901	705							1	3	3							
8	22351	1566							2	4	5	2						
9	83597	5508							1	9	8	2						
10	425417	27899				2	8	19	54	117	97	40	9	3	1			
11	785260	50866	1	1	1	1	2	5	46	144	73	31	4	1				
12	94294	6001							10	31	23	9	1					
ALL	1436655	94954	1	2	4	8	22	84	359	725	709	384	102	32	11	4	2	1
	DESCENT																	
2	4575	744		1	1	3	10	40	136	228	277	176	67	26	7	2	1	
3	7077	985				2	6	21	93	169	203	120	38	11	2			
4	17702	2058		1	1	3	5	21	97	208	272	142	35	9	3	1		
5	16594	1667						4	31	65	91	37	7	1				
6	17606	1595						1	9	24	39	19	6	1	1			
7	17843	1460							8	22	21	10	2	1				
8	18886	1437							1	3	6	2						
9	29962	2119		2	3	3	5	8	18	33	34	19	7	3	2	1	1	
10	39273	2677							1	6	4							
11	19251	1260							2	5	3	2	1					
12	1263	80																
ALL	190031	16082		4	6	11	26	96	397	764	950	528	163	53	15	4	2	

Table.1 (cont'd.)

C.T. 4

GUSTS ENCOUNTERED BY THE SUPER VC 10 , CALCULATED BY THE DISCRETE GUST METHOD

NUMBER OF TIMES THAT EACH GUST SPEED (M/S EAS) WAS EXCEEDED

ALT BAND	DISTANCE KM	TIME MIN	DOWNWARD								UPWARD									
			10	8	7	6	5	4	3	2.5	2.5	3	4	5	6	7	8	10	12	14
TAKE OFF																				
ALL	8202	1329		4	10	23	61	146	314	434	705	496	212	81	31	10	3			
LANDING																				
ALL	4954	1104	1	8	22	53	125	251	446	578	1680	1365	869	530	328	210	128	51	15	2
CLIMB																				
2	901	119				1	2	7	15	21	42	31	13	4						
3	2975	358				3	6	17	43	62	106	72	28	9	4	1				
4	13836	1485	1	2	3	5	10	27	72	118	202	130	53	16	5	1				
5	13814	1338			1	1	3	8	28	50	104	61	15	1						
6	12524	1110							2	4	8	5	2	1						
7	19599	1608				1	2	5	13	20	51	27	8	3	1					
8	19605	1504					1	4	9	16	27	15	5	2	1					
9	44750	3151						2	5	8	24	9	1							
10	54842	3622							6	19	33	15	3	1						
11	23064	1459							3	6	14	5								
12	2217	135								1	2	1								
ALL	208127	15889	1	2	4	11	24	69	196	324	611	371	129	38	12	3				
CRUISE																				
1	3917	742				3	7	18	34	45	297	213	96	34	13	5	2			
2	7190	1186				1	7	29	81	120	504	341	136	47	15	5	3	1		
3	2711	371						3	22	41	94	58	19	5	2	1				
4	2506	303				1	3	3	7	13	32	20	6	1						
5	2330	258							2	3	13	7	2							
6	2085	215									13	7	3	1						
7	6215	505									1									
8	15724	1206							3	7	14	6	1							
9	67653	4659						1	2	7	12	4	1							
10	470937	30594					1	5	23	47	67	25	4	1						
11	671197	43230		1	1	3	8	25	106	222	250	110	24	11	5	2	1			
12	62008	3806									6	3	1							
ALL	1314473	87075		1	2	9	26	83	280	505	1302	794	292	101	36	14	6	1		
DESCENT																				
1	609	122				1	3	7	13	17	40	29	12	3						
2	6113	1017					3	13	42	66	322	221	90	32	11	5	2			
3	8209	1134					1	6	23	39	196	115	30	7	3	1				
4	17502	2042				2	7	17	57	101	279	156	45	10	2	1				
5	15331	1540				1	1	3	12	27	90	48	13	3	1					
6	14991	1370							2	11	49	23	6	2	1					
7	13913	1166					1	2	7	13	42	22	6	2	1					
8	14670	1128							1	6	15	6	2	1	1					
9	33508	2394						1	6	16	37	19	2							
10	29682	2003							3	8	13	5								
11	8733	559							4	7	10	5								
12	343	22																		
ALL	163604	14497			1	5	17	49	169	310	1093	647	206	59	20	7	2			

Table.1 (cont'd.)

C.T. 5

GUSTS ENCOUNTERED BY THE 707 , CALCULATED BY THE SPECTRAL GUST METHOD

NUMBER OF TIMES THAT EACH GUST SPEED (M/S EAS) WAS EXCEEDED

ALT BAND	DISTANCE KM	TIME MIN	DOWNWARD									UPWARD								
			14	12	10	8	7	6	5	4	3	3	4	5	6	7	8	10	12	14
	TAKE OFF																			
ALL	16390	2456		1	4	17	50	130	292	599	1090	982	547	273	119	44	15	2		
	LANDING																			
ALL	7573	1522		1	2	8	16	34	72	137	244	208	122	65	29	12	6	2	1	
	CLIMB																			
2	1501	195				1	2	5	10	20	34	23	15	9	5	3	2	1		
3	3626	431					1	5	25	65	130	84	36	13	5	2	1			
4	14786	1584				1	4	10	33	94	238	231	97	37	16	6	1			
5	15825	1523				1	3	8	17	42	109	90	34	14	7	3	2			
6	17272	1533							1	11	42	32	10	3						
7	19767	1640						1	5	12	38	30	8	3						
8	24382	1874							1	6	23	11	5	3	2	1	1			
9	35069	2500						1	3	14	60	66	23	9	3	1				
10	52606	3547							3	12	54	32	6	2	1					
11	26412	1726								2	12	8	1							
12	2270	146																		
ALL	213517	16699				3	10	30	98	276	740	607	234	93	39	18	7	1		
	CRUISE																			
1	2418	445	1	1	2	3	4	11	28	60	107	159	93	46	19	8	5	3	1	1
2	6053	1007					2	16	65	171	343	368	188	81	31	16	6			
3	2801	370				1	2	4	11	31	75	101	43	16	6	2	1			
4	1700	198						1	5	11	25	26	10	3	2	2	1			
5	2118	234				1	1	2	3	7	18	23	9	2	1					
6	1744	155								2	3	10	2							
7	8901	705								1	10	8	1							
8	22351	1566								2	8	8	2							
9	83597	5508								2	20	15	2							
10	425417	27899				2	6	13	23	55	187	161	41	13	6	2	1			
11	785260	50866		1	1	1	1	2	8	41	233	120	29	7	1					
12	94294	6001							2	11	54	39	9	2						
ALL	1436655	94954	1	2	3	8	17	49	146	393	1082	1037	430	172	66	30	14	3	1	1
	DESCENT																			
2	4575	744			1	4	9	26	68	157	315	371	200	100	51	26	10	1		
3	7077	985				3	6	14	41	111	243	282	138	61	27	11	3			
4	17702	2058		1	1	3	5	12	41	119	330	414	169	64	22	9	4			
5	16594	1667						2	11	37	102	156	46	14	4	1				
6	17606	1595						1	3	12	46	69	23	11	4	1	1			
7	17843	1460							1	10	39	38	12	4	2	1				
8	18886	1437								1	11	13	3	1						
9	29962	2119		1	2	3	4	7	10	21	54	53	22	10	6	4	2	1	1	
10	39273	2677								2	17	12								
11	19251	1260								2	9	6	2	1						
12	1263	80																		
ALL	190031	16082		2	5	13	25	61	175	472	1166	1415	615	267	116	52	21	3	1	

Table.1 (concl'd.)

C.T. 6

GUSTS ENCOUNTERED BY THE SUPER VC 10 , CALCULATED BY THE SPECTRAL GUST METHOD

NUMBER OF TIMES THAT EACH GUST SPEED (M/S EAS) WAS EXCEEDED

ALT BAND	DISTANCE KM	TIME MIN	DOWNWARD									UPWARD									
			14	12	10	8	7	6	5	4	3	3	4	5	6	7	8	10	12	14	16
TAKE OFF																					
ALL	8202	1329		1	7	22	47	96	183	319	511	844	509	275	133	63	30	5			
LANDING																					
ALL	4954	1104		1	11	44	88	161	268	418	623	1790	1296	912	624	423	297	140	67	30	10
CLIMB																					
2	901	119				1	1	3	8	15	24	47	29	16	7	2					
3	2975	358				2	4	9	21	41	72	124	70	35	15	6	3				
4	13836	1485	1	1	2	5	8	16	34	73	149	250	130	66	30	11	5	1			
5	13814	1338				1	3	5	11	29	68	132	60	23	5						
6	12524	1110							1	2	5	10	5	3	1	1					
7	19599	1608				1	1	3	5	12	24	64	25	10	5	2	1				
8	19605	1504						2	5	9	21	35	14	6	3	2	1				
9	44750	3151							2	4	11	34	8	1							
10	54842	3622							1	6	29	45	13	5	2	1					
11	23064	1459								3	7	19	4								
12	2217	135									1	2									
ALL	208127	15889	1	1	2	10	17	38	87	194	410	763	360	164	67	26	11	1			
CRUISE																					
1	3917	742				3	7	13	23	36	52	356	223	128	65	28	14	4	1		
2	7190	1186				1	5	17	43	86	148	634	367	194	93	43	19	4	2	1	
3	2711	371						1	6	24	55	123	63	29	12	5	2				
4	2506	303				2	3	3	4	8	17	43	21	9	4	1					
5	2330	258							1	2	5	17	8	4	1						
6	2085	215										18	8	4	3	1					
7	6215	505										2									
8	15724	1206								3	11	24	7	2	1						
9	67653	4659							1	2	13	18	4	1							
10	470937	30594					1	1	6	21	62	91	21	5	2	1					
11	671197	43230		1	1	3	6	11	30	95	296	326	89	26	14	8	4	1			
12	62008	3806									1	6	2	1							
ALL	1314473	87075		1	1	9	21	47	114	278	660	1658	812	403	195	87	40	9	3	1	
DESCENT																					
1	609	122				2	3	5	9	14	20	49	31	18	8	2					
2	6113	1017					3	9	22	47	86	401	239	129	64	29	14	4	1		
3	8209	1134					1	3	10	25	51	263	127	50	19	6	3	1			
4	17502	2042				3	6	11	25	62	138	386	172	69	27	8	3				
5	15331	1540				1	1	2	4	14	39	129	53	21	7	2	1				
6	14991	1370								3	19	73	26	9	4	2	1				
7	13913	1166				1	1	1	3	8	19	62	24	10	4	2	1				
8	14670	1128								1	13	25	6	2	2	1	1				
9	33508	2394						1	2	7	31	57	21	6	1						
10	29682	2003								3	14	22	6								
11	8733	559								2	7	12	3								
12	343	22																			
ALL	163604	14497				6	15	32	76	186	437	1477	710	315	135	54	24	5	1		

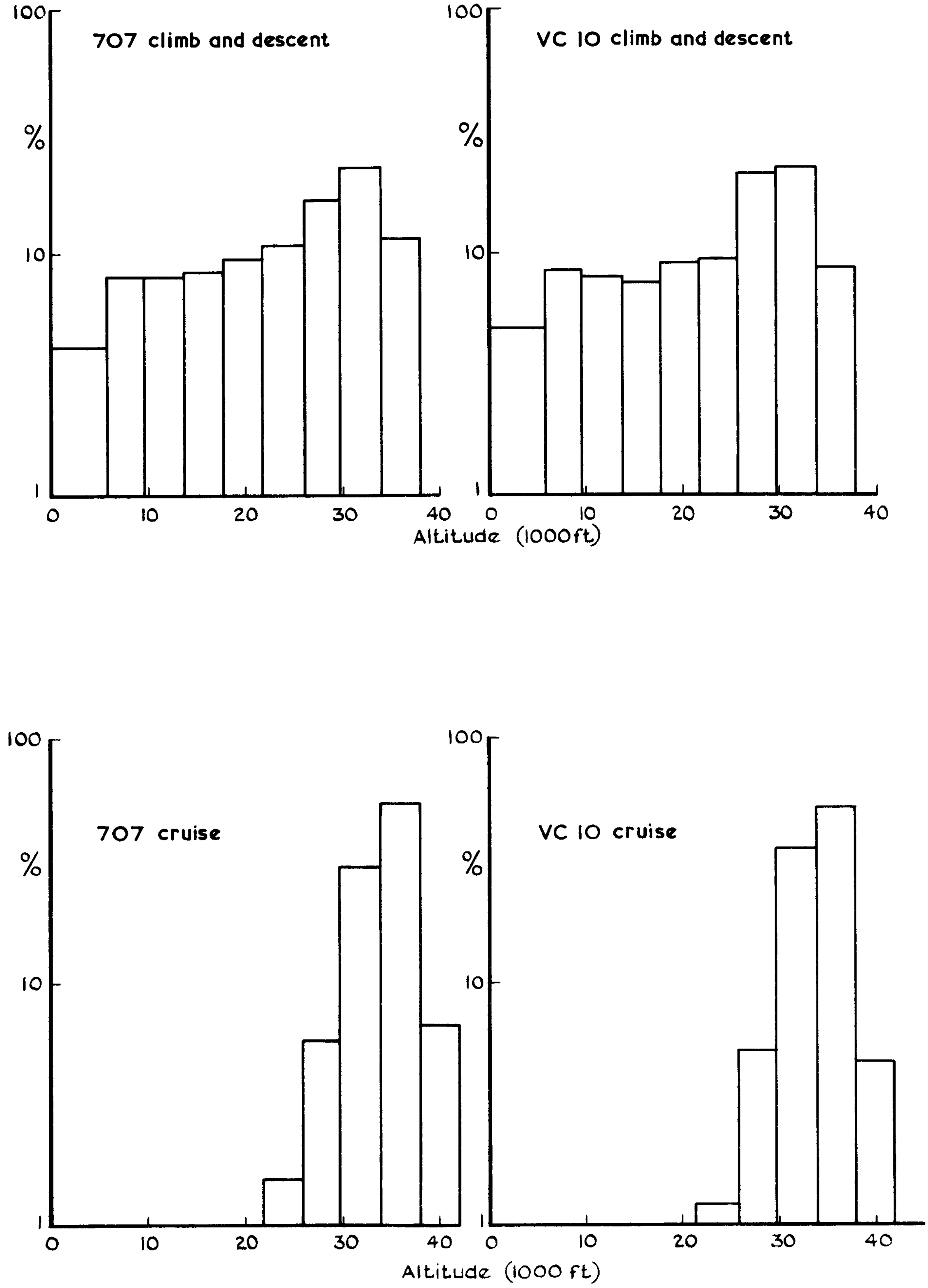

Fig. 1a Distance flown in each altitude band, as a percentage of the total distance recorded at all altitudes in the respective flight conditions

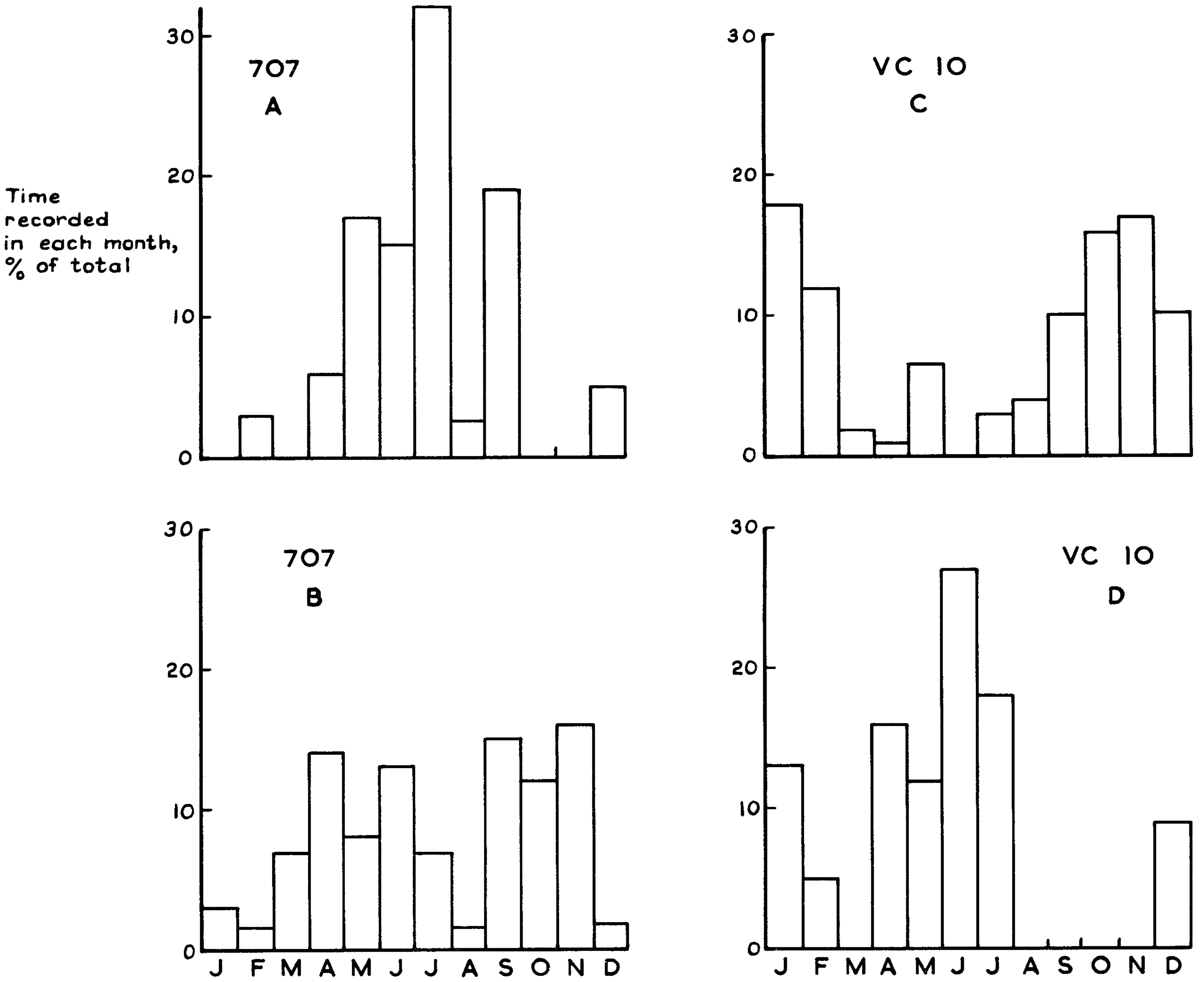

Fig. 1b Annual distribution of flying time recorded on each aircraft

Total distance	km x 1000
Climb	214
Cruise	1437
Descent	190

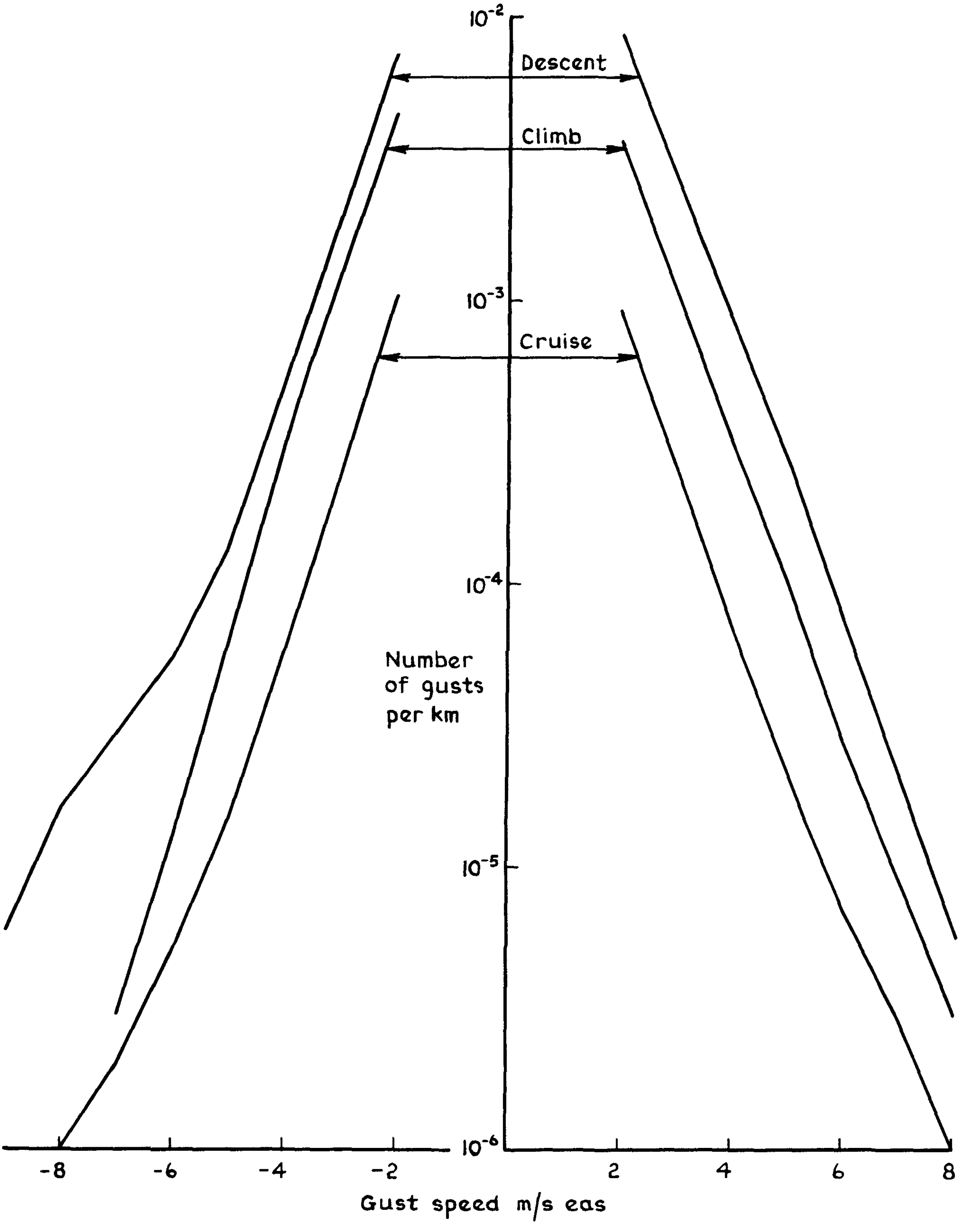

Fig. 2 Gusts encountered by 707 aircraft at all altitudes. Calculated with discrete gust response factors

Total distance	km x 1000
Climb	208
Cruise	1314
Descent	164

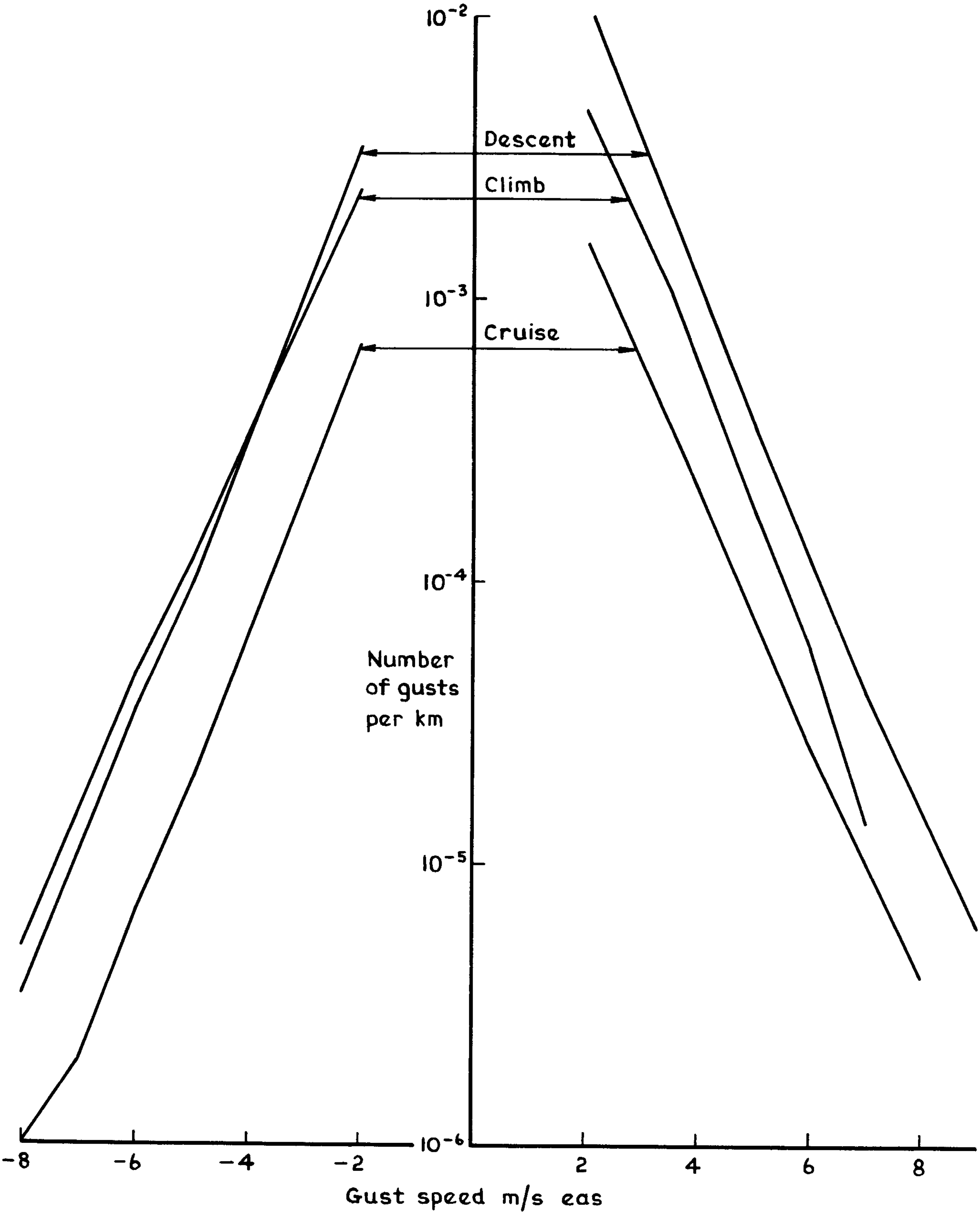

Fig. 3 Gusts encountered by VC 10 aircraft at all altitudes. Calculated with discrete gust response factors

Total distance	km x 1000
Climb	214
Cruise	1437
Descent	190

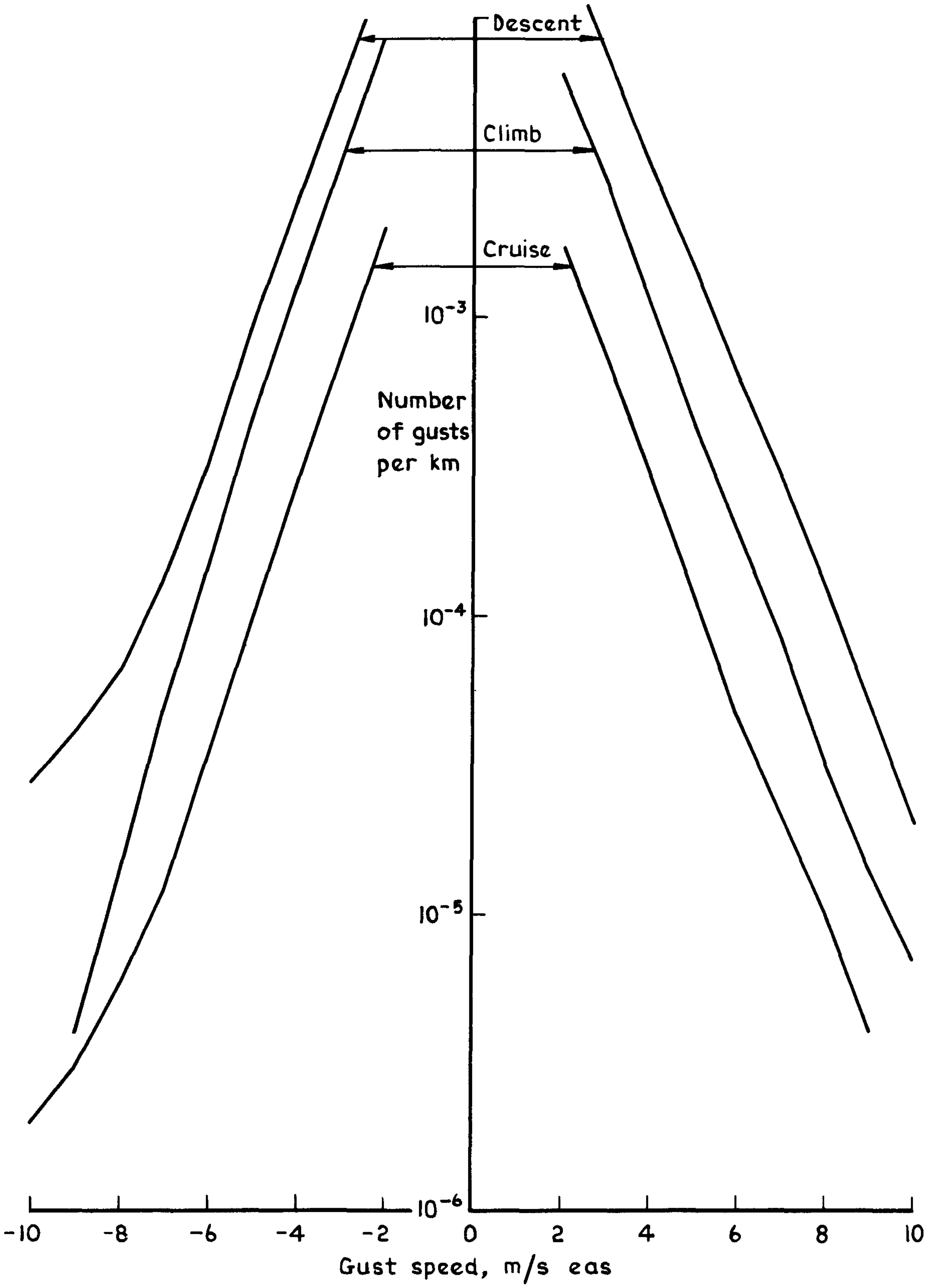

Fig.4 Gusts encountered by 707 aircraft at all altitudes. Calculated with spectral gust response factors

Total distance	km x 1000
Climb	208
Cruise	1314
Descent	164

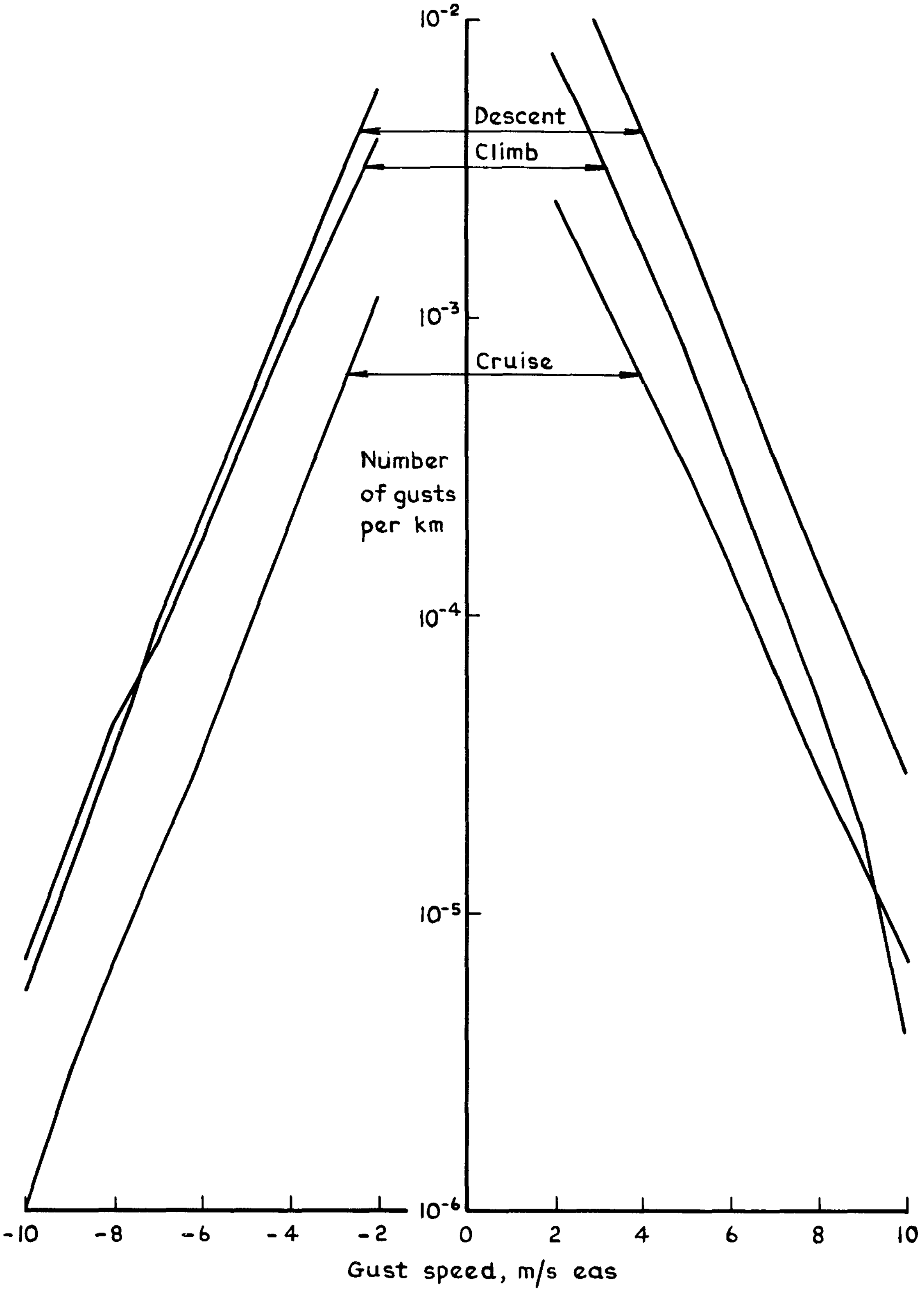

Fig.5 Gusts encountered by VC10 aircraft at all altitudes. Calculated with spectral gust response factors

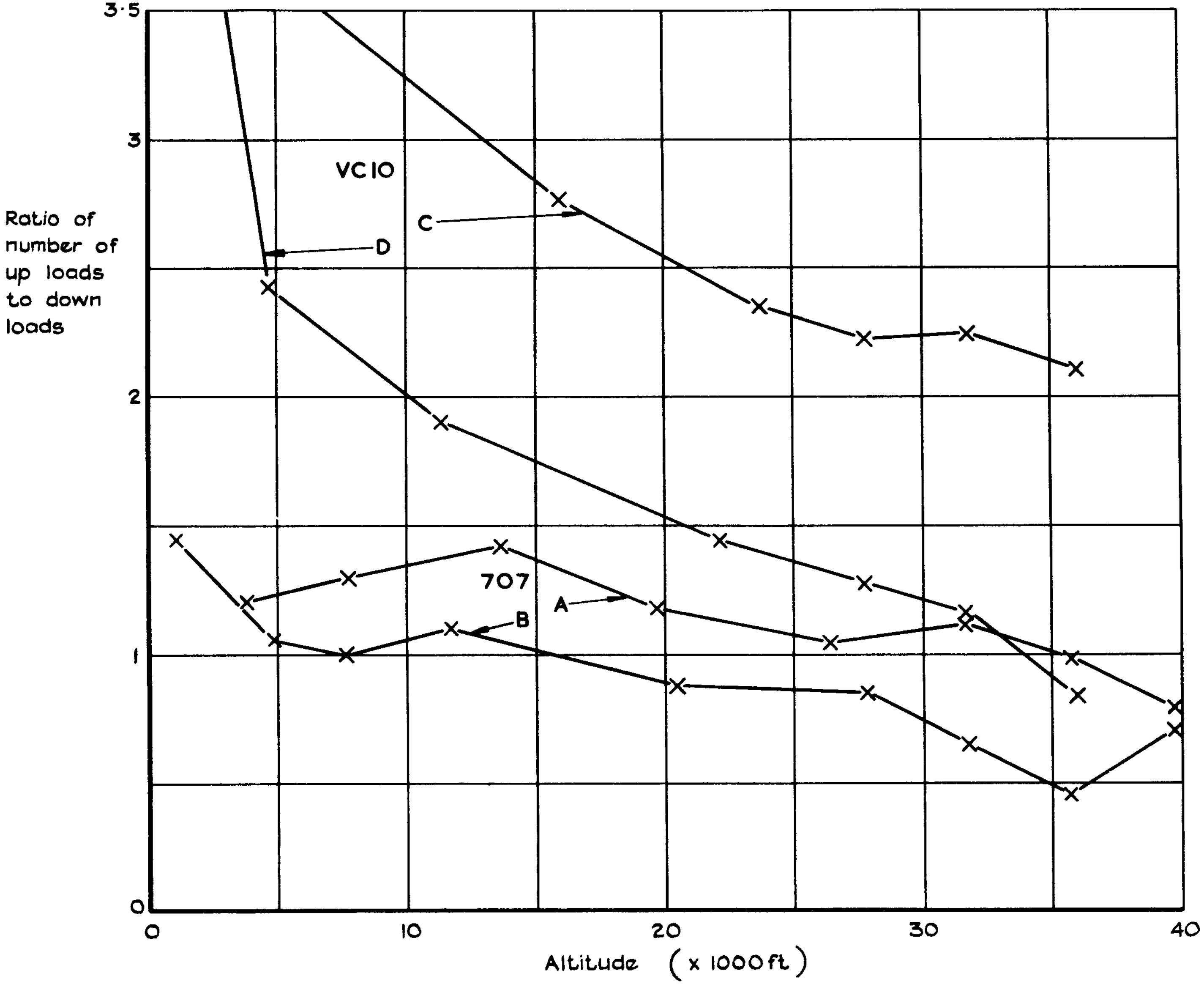

Fig. 6 Variation with altitude of the ratio of number of up loads to down loads at the 0·2g acceleration increment level. Climb, cruise and descent

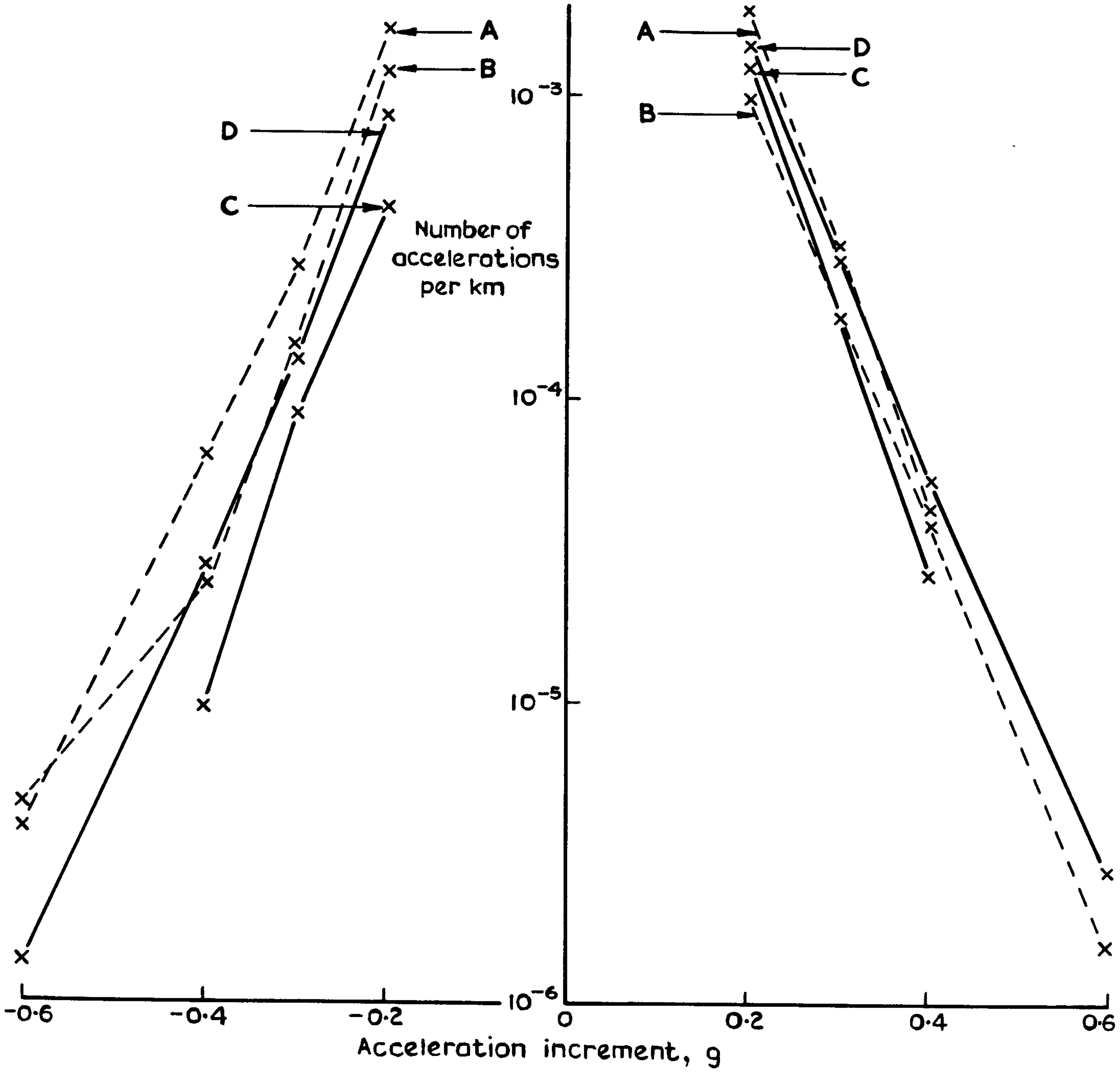

Fig.7 Accelerations recorded during climb, cruise and descent at all altitudes

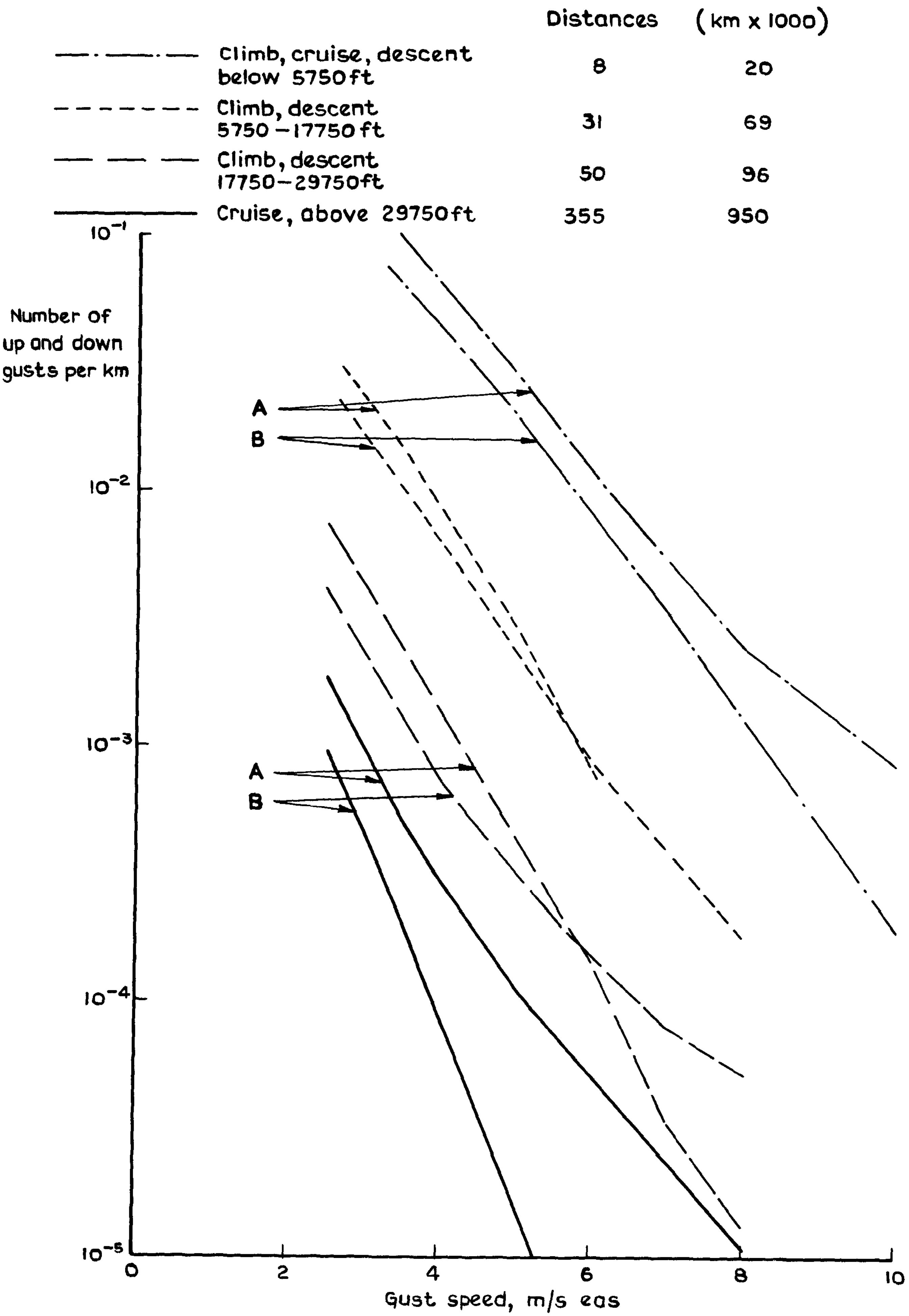

Fig.8 Gusts encountered by individual 707 aircraft, calculated with spectral gust response factors

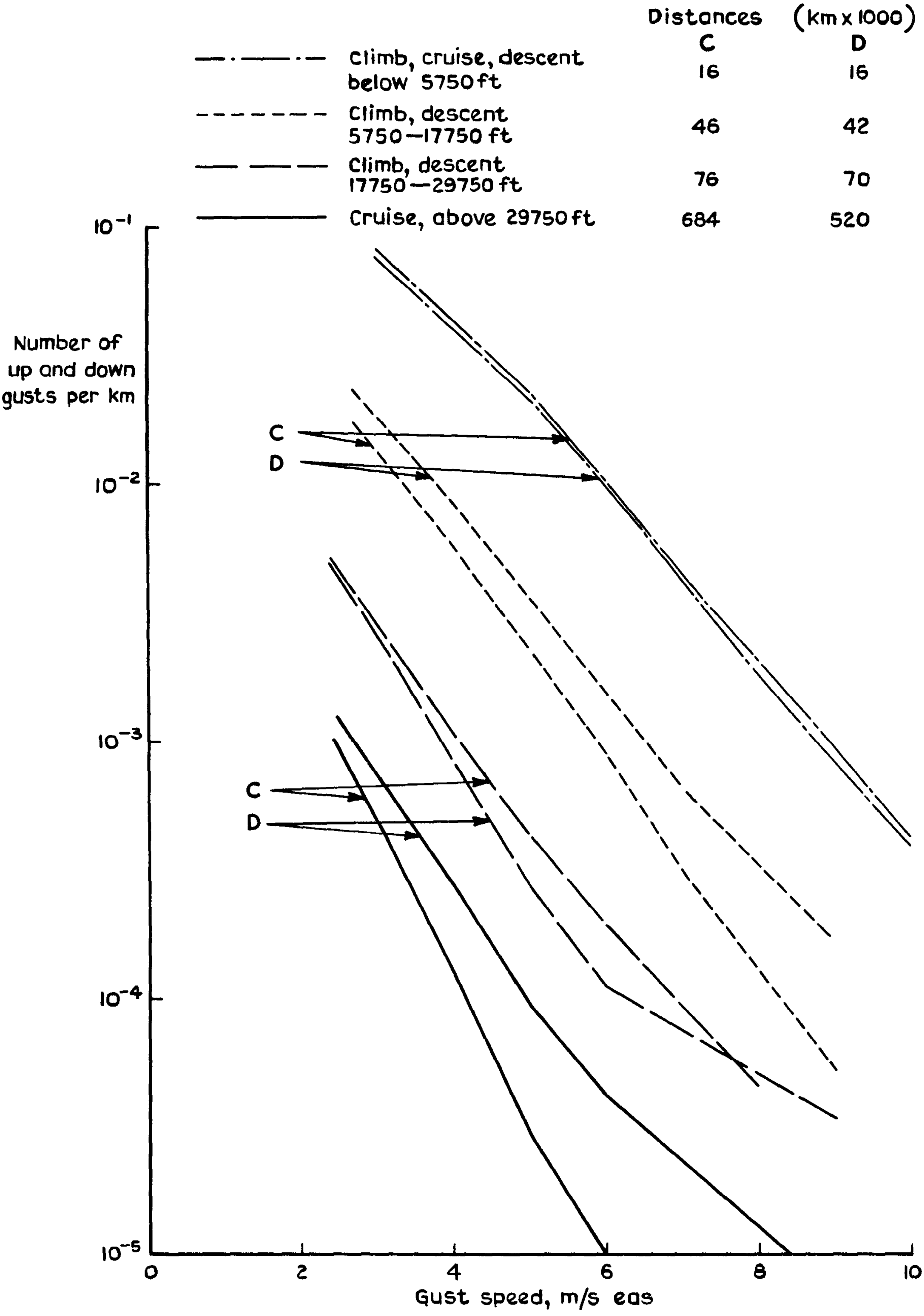

Fig. 9 Gusts encountered by individual VC 10 aircraft, calculated with spectral gust response factors

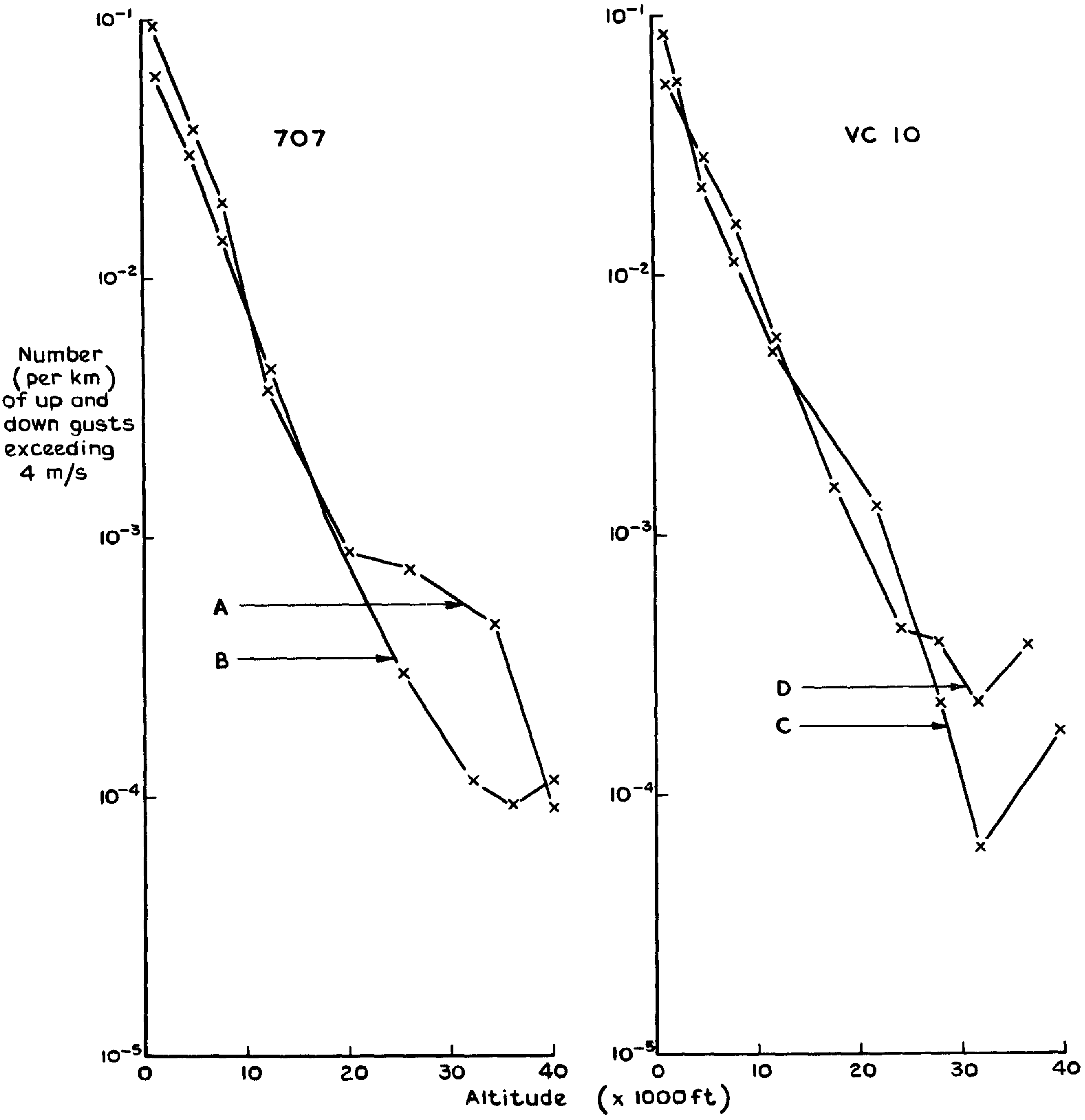

Fig.10 Variation with altitude of the frequency of 4m/s gusts calculated with spectral gust response factors. Data from climb, cruise and descent combined

Printed in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough. Dd. 505716 K4 1/74.

ARC CP No.1281 533.6.048.5
August 1972

Kaynes, I. W.

GUST LOADS ON 707 AND VC 10 AIRCRAFT

Counting accelerometers have been used to record the centre of gravity normal accelerations on 707 and VC 10 aircraft during passenger services covering 1 870 000 km and 1 700 000 km respectively. A significant difference is found between the frequency of loads on two nominally identical 707 aircraft and the relationship of this to differences in autopilot characteristics is discussed. The most severe loads encountered by each aircraft are described.

Cut here

ARC CP No.1281 533.6.048.5
August 1972

Kaynes, I. W.

GUST LOADS ON 707 AND VC 10 AIRCRAFT

Counting accelerometers have been used to record the centre of gravity normal accelerations on 707 and VC 10 aircraft during passenger services covering 1 870 000 km and 1 700 000 km respectively. A significant difference is found between the frequency of loads on two nominally identical 707 aircraft and the relationship of this to differences in autopilot characteristics is discussed. The most severe loads encountered by each aircraft are described.

ARC CP No.1281 533.6.048.5
August 1972

Kaynes, I. W.

GUST LOADS ON 707 AND VC 10 AIRCRAFT

Counting accelerometers have been used to record the centre of gravity normal accelerations on 707 and VC 10 aircraft during passenger services covering 1 870 000 km and 1 700 000 km respectively. A significant difference is found between the frequency of loads on two nominally identical 707 aircraft and the relationship of this to differences in autopilot characteristics is discussed. The most severe loads encountered by each aircraft are described.

Cut here

DETACHABLE ABSTRACT CARDS

DETACHABLE ABSTRACT CARDS

C.P. No. 1281

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
41 The Hayes, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY
or through booksellers

C.P. No. 1281

ISBN 011 470865 7