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A Review of Information on the Frequency of Gusts at Low Altitude

by

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COMMUNICATED BY THE DEPUTY CONTROLLER AIRCRAFT (RESEARCH AND DEVELOPMENT)
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SUMMARY

The paper reviews information from several sources on atmospheric gusts at altitudes below 1000 feet. Comparison is made between gust statistics obtained from passenger transport aircraft and those acquired during special investigations.

The information gives reliable average figures for passenger transport operations but, owing to the wide variation of gust frequencies under different conditions, it is concluded that for military aircraft flying at low level, a more detailed knowledge of operating conditions is necessary for reliable estimates of gust frequencies to be made.

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CONTENTS

1 INTRODUCTION

Information is required on the frequency of gusts at low altitude for the purpose of aircraft fatigue life estimation. This paper reviews the available data, and estimates gust frequencies for use in fatigue life calculations.

2 DATA AVAILABLE

2.1 Operational data

For many years counting accelerometer data have been collected from passenger transport aircraft. A short part of the flying immediately after take-off and before landing is necessarily at low altitude, and some of the remaining flying is also below 1000 ft. The information from these records should provide a reasonable estimate of gust frequencies on a worldwide basis encountered by passenger transport aircraft. The information is basically that given in Ref.1, although some re-analysis has been done by more up-to-date methods.

2.2 Observations in N. Africa

An extensive investigation of low-level gusts in North Africa, known as Operation Swifter, was made in 1959/60. This provides detailed information on the variation of gust frequencies with terrain, season and altitude[2].

2.3 Observations in the United Kingdom

Special low-level investigations by Heath-Smith[3] and Wells[4] are also worthy of note. However, each investigation set out to examine a specific problem, so that turbulent occasions were favoured during the flying and the samples are not, therefore, representative.

3 EXAMINATION OF DATA

3.1 Operational data

The counting accelerometer data have been classified as follows:

(i) "Initial climb and final descent", consisting of data obtained from the first interval after take-off and the last interval before landing.

(ii) Climb and descent, other than the above, is obtained from intervals during which the altitude changes by 2000 ft or more.

(iii) Cruise, during which the altitude changes by less than 2000 ft during the interval.

Table 1 gives gust frequencies estimated for these three categories, shown plotted in Fig.1. There is little to choose between the gust frequencies for the first two of these, but the third, for cruise, is significantly better except at the high gust velocities. Much of this cruise information has been recorded by aircraft cruising low over the sea (e.g., Bristol Freighter ferry services), and this would account for the difference over most of the range. However, the low altitude cruise will also include stand-off flying in the vicinity of airfields, and it is likely that manoeuvre loads affected the shape of the "tail" of this curve. The other two curves also show slight signs of the influence of manoeuvre loads. At the lower gust velocities the curve is somewhat steeper than the standard curve of Ref.1, Fig.4. This is to be expected at low level, since the larger gusts probably require a greater height in which to build up. However, at the higher gust velocities the curve flattens off to a greater extent than would be expected, and this could be due to manoeuvre loads.

It is considered that on the whole both the climb and descent categories are reasonably representative of conditions experienced at these altitudes. The figures have therefore been combined and plotted in Fig.2 together with an empirical curve fitted to the observed values.

3.2 Observations in N. Africa

For the purpose of this paper, the Swifter observations have been used to give three gust spectra: the first for all flying at 200 ft over land, the second for all flying at 200 ft over sea, and the third, as an example of very severe conditions, for flying at midday in the summer over hilly desert at 200 ft. These estimates are given in Table 2, and shown plotted in Fig.3. The most striking fact to emerge is the wide disparity between the three conditions, there being a factor of over 100 between the frequencies of 10 ft/sec gusts or greater over the sea and over land in the most severe conditions. This emphasises the importance of knowing under what conditions an aircraft will operate.

A comparison of the curve for all flying over the land with the climb and descent curves of Fig.1 shows that frequencies of the 10 ft/sec gusts agree quite closely. The Swifter observations, however, contain fewer gusts of the higher velocities. How far this is due to differences in flying procedure, it is difficult to say. Probably the operational data contain more manoeuvre loads; reference has already been made to indications of this. It is likely that there are very few manoeuvre loads in the Swifter data, since the pilots were instructed to keep these to a minimum, and most of the flying was over flat terrain - even the ground referred to as "hilly desert" was more in the nature of an eroded plateau rather than of a rolling hilly character.

However, it may well be that high winds over country of such a rolling nature and containing more obstacles will, in any case, produce gusts of the higher velocities. For the purposes of life estimation it might be wiser to assume a gust distribution more in agreement with Fig.2 than with Fig.3.

3.3 Variation with height

The most direct evidence of the way in which gust frequencies change with height at altitudes under 1000 ft is given by the Swifter experiment in which three aircraft flew almost simultaneously at respective heights of 200 ft, 400 ft and 600 ft. (On some of these scheduled flights only two aircraft were available. In these cases the flying was at 200 ft and 400 ft. These occasions were fairly evenly spread throughout the year.)

The numbers of gusts encountered in all these comparative flights made over land (including both flat and hilly desert) are given in Table 3, and the corresponding relationships shown plotted in Fig.4. It will be seen that at 10 ft/sec there is very little change in frequency with height but the slope of the distribution tends to become slightly steeper with decreasing altitude, confirming the trend inferred in para. 3.1.

The frequency of gusts of 10 ft/sec or more can also be derived from the counting accelerometer records at different heights. The height bands are much coarser in this case than for Operation Swifter, but the gust frequencies for the first few height bands can, nevertheless, be examined to see if they are compatible with the Swifter results.

The frequencies of gusts of 10 ft/sec or more for all climb and descent (classes (i) and (ii) of para. 3.1) are given in Table 4 and shown plotted in Fig.5. It is seen that a flattening off of the relationship below about 1000 ft is quite in keeping with the general trend, and it is probably sufficient to assume a value of one gust of 10 ft/sec or more for every 3 miles flown for all altitudes under 1000 ft.

4 VARIABILITY OF CONDITIONS

4.1 Variability of conditions in N. Africa

It has already been mentioned in para. 3.2 that the numbers of gusts encountered vary between very wide limits under different conditions. As shown in Fig.3, during the experimental work in North Africa the average figures over land and sea for the year's flying differed by a factor of about 20 for gusts of 10 ft/sec or more.

4.2 Variability of conditions in the United Kingdom

Heath-Smith's work with a Hunter aircraft, flying over Southern England and the English Channel, confirms this large difference between land and sea. During flights extending over a period of about ten months, usually on windy occasions, about eight times as many gusts of 10 ft/sec or greater were encountered over land as over the sea. The effect of wind on the frequency of gusts over the land was also shown. Dividing Heath-Smith's data into flights, with winds of 7 knots and below and 8 knots and above, gives the following comparison:

Wind speed range (knots)	Mean wind speed (knots)	Number of gusts of 10 ft/sec or greater per mile
0 - 7	3.7	0.203
8 - 22	11.1	1.05

An increase in the average wind speed from 3.7 knots to 11.1 knots increased the frequency of gusts by five times.

Wells[4] has investigated the influence of wind speed and lapse rate on turbulence encountered on three routes over the U.K. These flights do not constitute a random sample, as they tended to be made on windy occasions and usually near the middle of the day. Thus, the frequency of gusts of 10 ft/sec or greater which were encountered was much greater than the overall figures for passenger transports given above:- over Wales and East Sussex, about six times as great, and over East Anglia twice as great.

The influence of wind speed and lapse rate are clearly shown; in most cases linear relations between numbers of gusts and these factors are indicated, although the data were not of sufficient quantity for firm numerical conclusions to be drawn.

5 CONCLUSIONS

It is clear that the frequency of gusts at low level can vary between very wide limits according to locality and weather conditions.

In estimating the fatigue life of a passenger transport aircraft, the average values of gust frequencies obtained from this kind of aircraft during typical operation is just what is required, but this is not necessarily true for military aircraft. For such aircraft, manoeuvre loads are likely to assume major importance, but in cases where gust loads are responsible for a large fraction of the fatigue damage, a detailed knowledge of operating conditions is necessary before a reliable estimate of fatigue life can be made.

A further point to be borne in mind is that a considerable increase in life could be achieved by flying as much as possible at selected times and places - in the early morning, at low wind speeds, and over the sea or a flat terrain.

Table 1

GUSTS ENCOUNTERED BELOW 1500 FT DURING PASSENGER TRANSPORT OPERATIONS

Initial climb and final descent

31590 miles at a mean altitude of 650 ft.

Gust velocity, v ft/sec	Number of gusts of v or greater	No. of gusts of v or greater per mile*
10	10912	3.45, - 1
15	1587	5.02, - 2
20	307	9.72, - 3
25	91	2.88, - 3
30	29	9.18, - 4
35	7	2.22, - 4
40	4	1.27, - 4

Other climb and descent

16400 miles at a mean altitude of 800 ft.

Gust velocity, v ft/sec	Number of gusts of v or greater	No. of gusts of v or greater per mile
10	5199	3.17, - 1
15	822	5.01, - 2
20	178	1.08, - 2
25	44	2.68, - 3
30	14	8.53, - 4
35	5	3.05, - 4
40	4	2.44, - 4
45	1	6.09, - 5

Cruise

82300 miles at a mean altitude of 900 ft.

Gust velocity, v ft/sec	Number of gusts of v or greater	No. of gusts of v or greater per mile
10	12026	1.46, - 1
15	1815	2.20, - 2
20	318	3.86, - 3
25	72	8.75, - 4
30	20	2.43, - 4
35	6	7.29, - 5
40	4	4.86, - 5
45	4	4.86, - 5
50	2	2.43, - 5
55	1	1.21, - 5

*The number of gusts per mile is given in standard floating point form, i.e. a number with one digit in front of the decimal point, followed by a comma and the power of ten by which it is multiplied.

Table 2

GUSTS ENCOUNTERED IN N. AFRICA

All flying at 200 ft over land (124 800 miles)

Gust velocity, v ft/sec	Number of gusts of v or greater	No of gusts of v or greater per mile
5	414 922	3.25
$7\frac{1}{2}$	139 549	1.12
10	34 173	2.74, - 1
15	4 098	3.28, - 2
20	431	3.45, - 3
25	69	5.53, - 4
30	8	6.41, - 5
35	3	2.40, - 5

All flying at 200 ft over the sea (43700 miles)

Gust velocity, v ft/sec	Number of gusts of v or greater	No of gusts of v or greater per mile
5	32932	7.54, - 1
$7\frac{1}{2}$	4503	1.03, - 1
10	714	1.64, - 2
15	21	4.81, - 4
20	5	1.15, - 4
25	2	4.58, - 5

Flying at midday in summer over hilly desert at 200 ft (2458 miles)

Gust velocity, v ft/sec	Number of gusts of v or greater	No of gusts of v or greater per mile
5	24349	9.91
$7\frac{1}{2}$	12880	5.24
10	5776	2.35
15	881	3.58, - 1
20	108	4.39, - 2
25	20	8.14, - 3
30	2	8.14, - 4

Table 3

GUSTS ENCOUNTERED IN N. AFRICA DURING COMPARATIVE FLIGHTS AT DIFFERENT ALTITUDES OVER FLAT AND HILLY DESERT

Altitude ft	Distance miles	Gust velocity v ft/sec	Number of gusts of v or greater	No of gusts of v or greater per mile
200	8270	5	56586	6.84
		7½	23928	2.89
		10	8090	9.78, - 1
		15	822	9.94, - 2
		20	81	9.79, - 3
		25	9	1.09, - 3
		30	1	1.21, - 4
400	8059	5	49263	6.11
		7½	22182	2.75
		10	8180	1.02
		15	903	1.12, - 1
		20	81	1.01, - 2
		25	5	6.20, - 4
		30	1	1.24, - 4
600	5130	5	28758	5.61
		7½	13683	2.67
		10	5356	1.04
		15	670	1.31, - 1
		20	85	1.66, - 2
		25	8	1.56, - 3
		30	2	3.90, - 4

Table 4

GUSTS ENCOUNTERED DURING CLIMB AND DESCENT BELOW 13500 FT BY PASSENGER TRANSPORT AIRCRAFT

Mean height ft	Miles	No of gusts of 10 ft/sec or more	No of gusts of 10 ft/sec or more per mile
702	47 999	16111	3.36, - 1
2493	68 871	14475	2.10, - 1
4553	91 408	9260	1.01, - 1
7526	236 878	11481	4.85, - 2
11560	169 102	3149	1.86, - 2

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2	N. I. Bullen	Gusts at low altitude in North Africa. A.R.C. Current Paper 581. September 1961
3	J. R. Heath-Smith	Atmospheric turbulence encountered by a Hunter aircraft at low altitude. R.A.E. Tech. Note Structures 245. July 1958 ARC 20627
4	E. W. Wells	Low altitude gust measurements over three routes in the U.K. ARC CP. No.676 October 1962

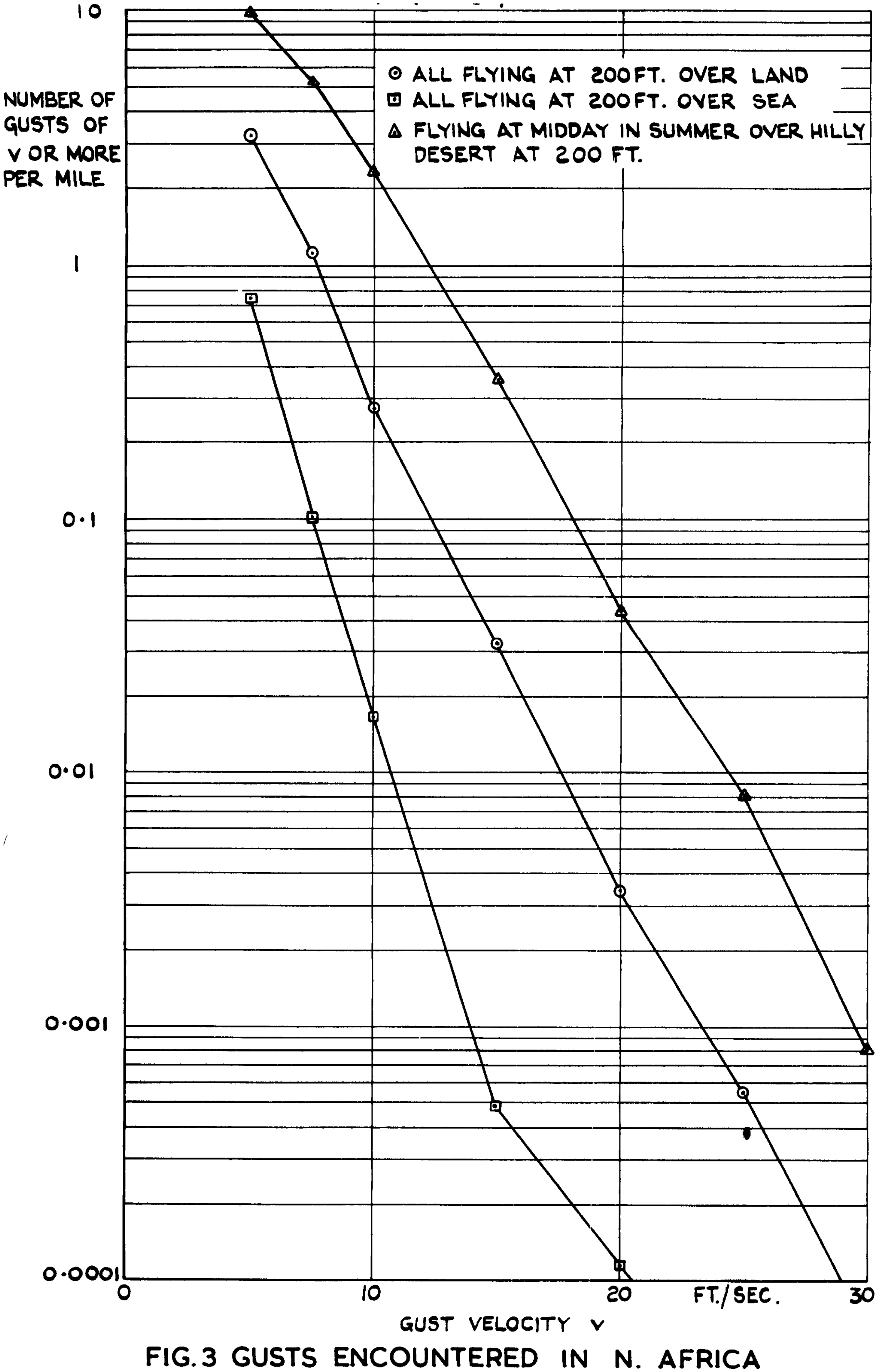

FIG. 3 GUSTS ENCOUNTERED IN N. AFRICA

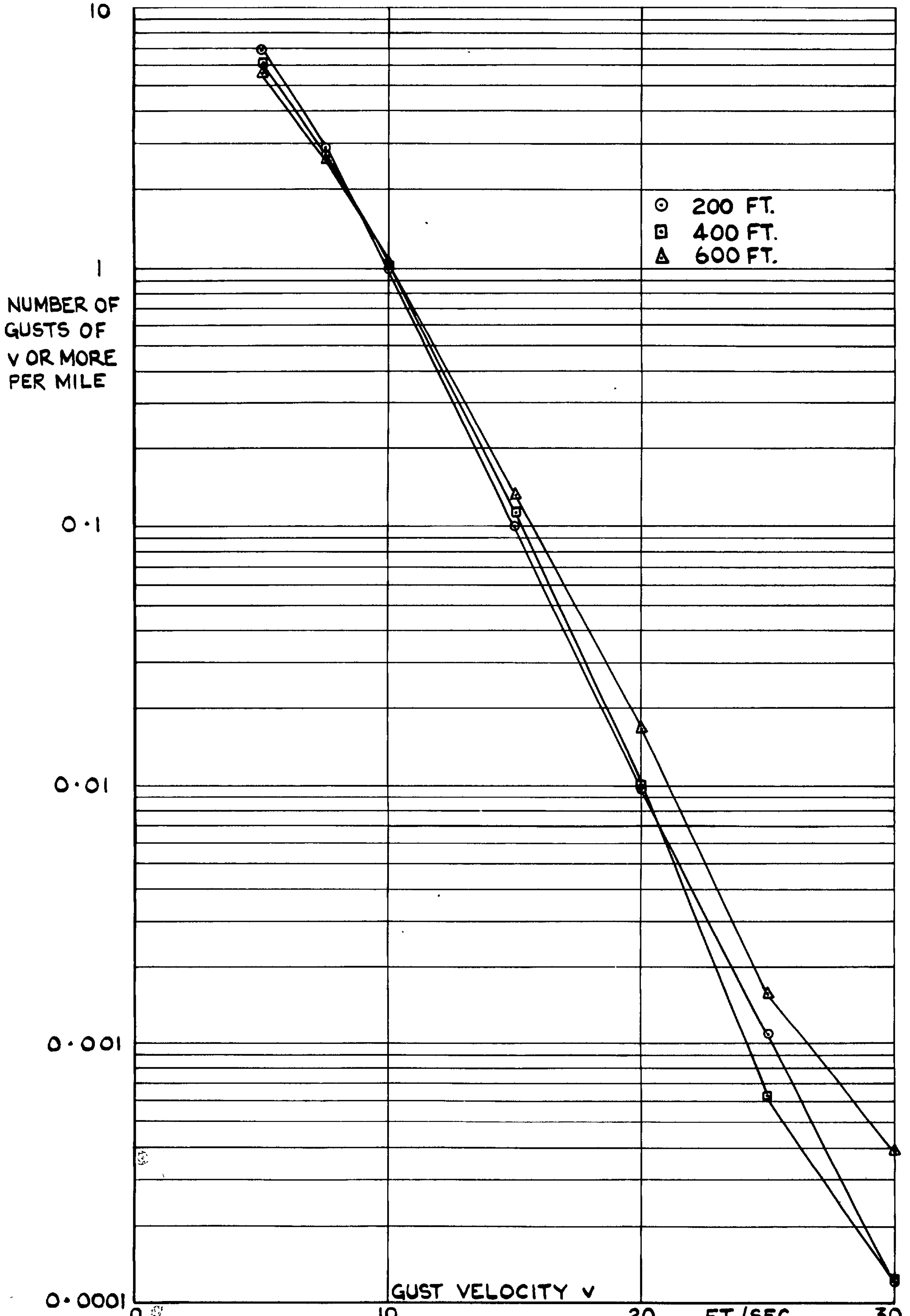

FIG. 4 GUSTS ENCOUNTERED IN N. AFRICA DURING COMPARATIVE FLIGHTS AT DIFFERENT ALTITUDES OVER FLAT AND HILLY DESERT

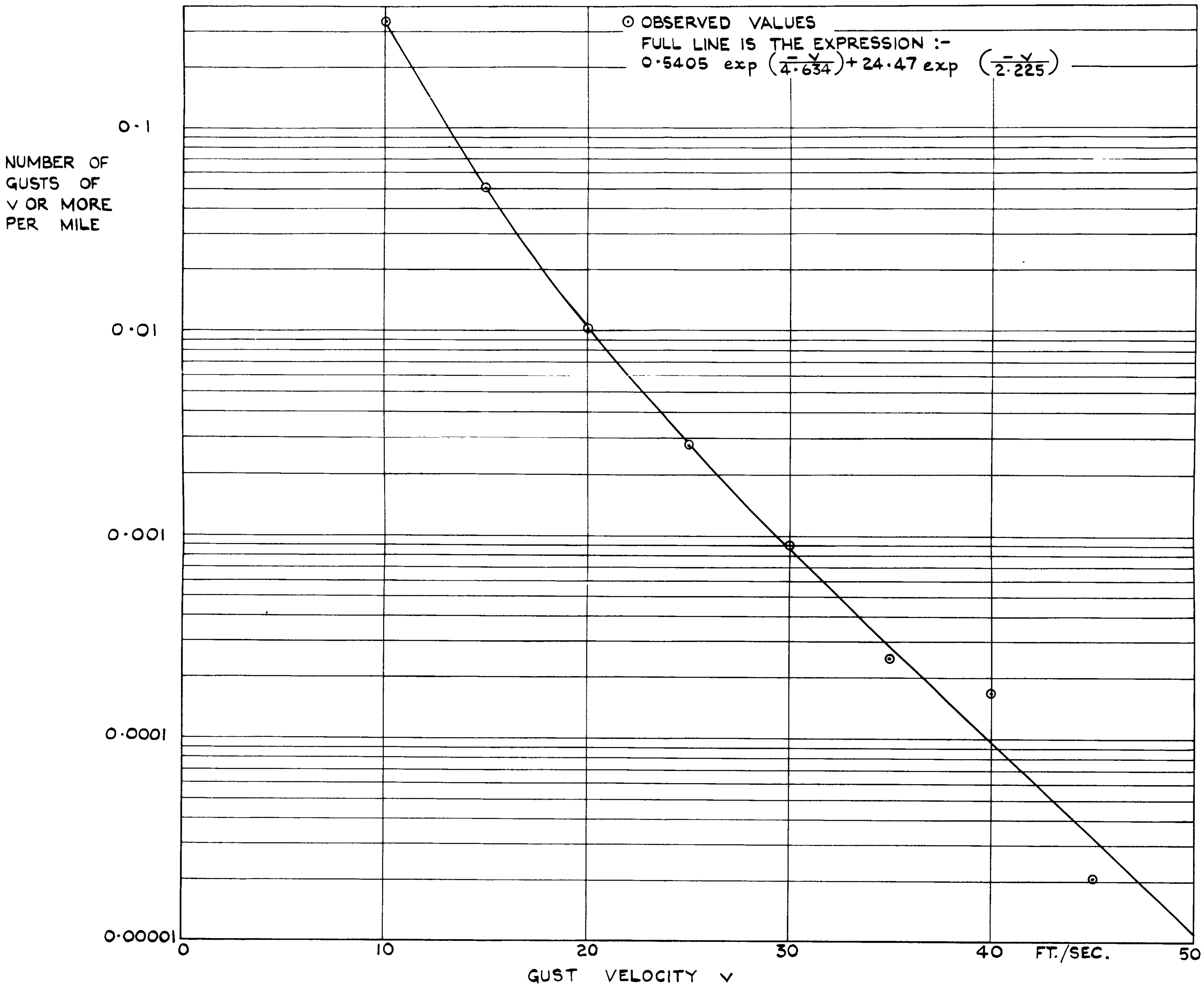

FIG. 2 GUSTS ENCOUNTERED BY PASSENGER TRANSPORT AIRCRAFT DURING CLIMB AND DESCENT BELOW 1500 FT.

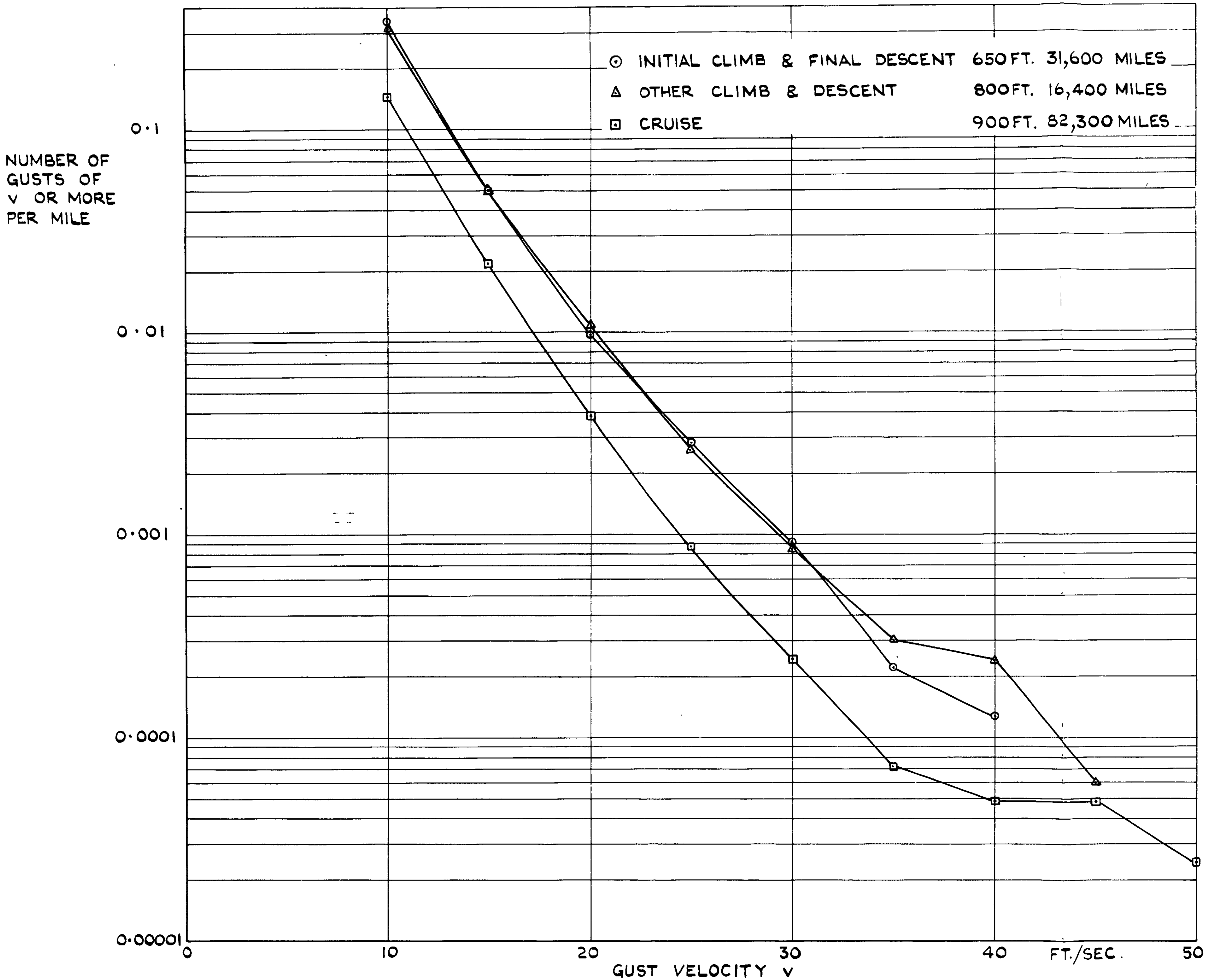

FIG. I GUSTS ENCOUNTERED BELOW 1500 FT. DURING PASSENGER TRANSPORT OPERATIONS

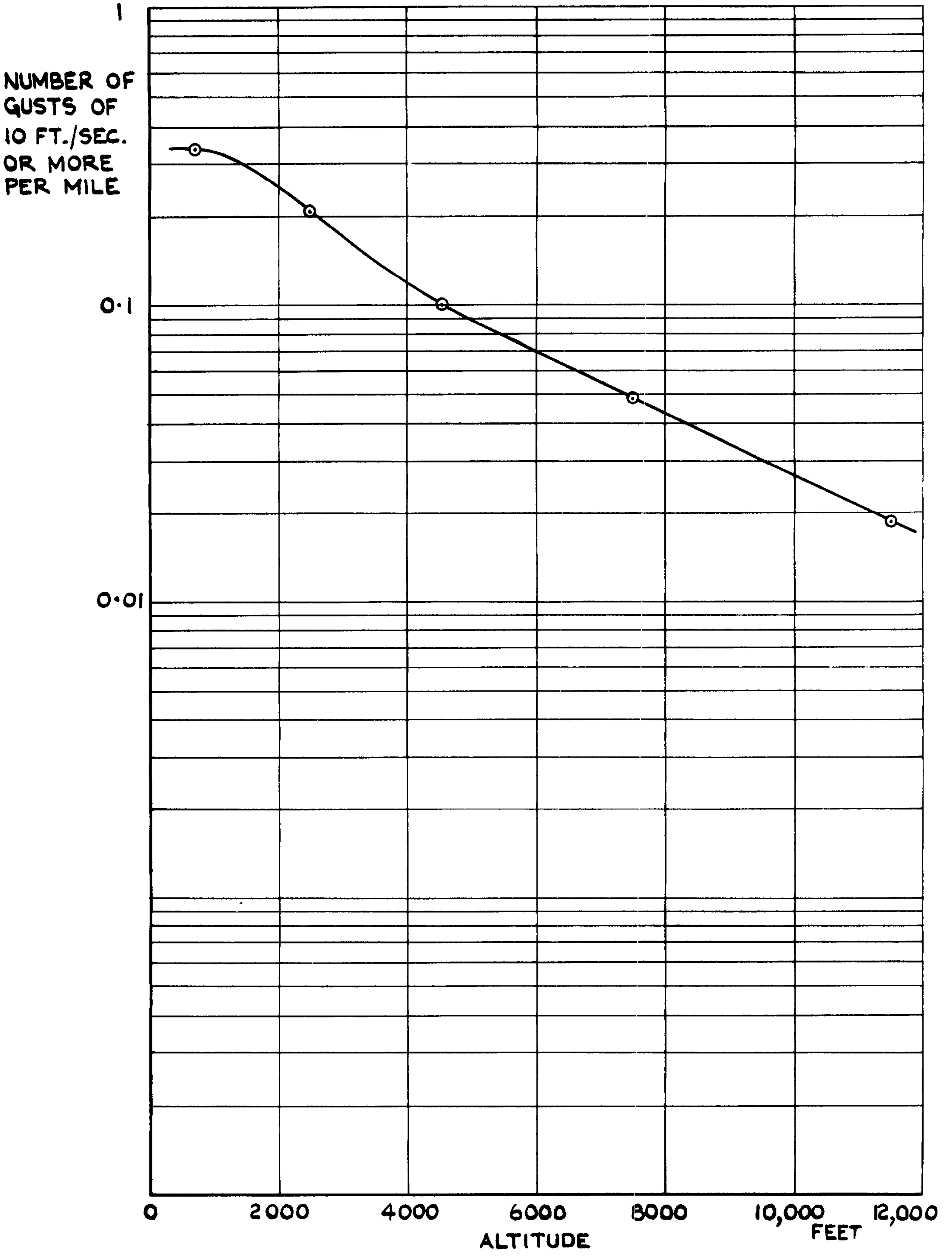

FIG. 5 GUSTS ENCOUNTERED DURING CLIMB AND DESCENT BELOW 13,500 FT. BY PASSENGER TRANSPORT AIRCRAFT

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