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The Variation of Gust Frequency with Gust Velocity and Altitude

By

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SUMMARY

Information on atmospheric turbulence obtained from counting accelerometer records is examined and relations giving the variation of gust frequency with gust velocity and altitude are obtained. The results are summarized in a form convenient for use in estimating the fatigue life of an aircraft.

LIST OF CONTENTS

		Page
1	Introduction	3
2	The variation of gust frequency with gust velocity	3
3	The variation of gust frequency with altitude	5
4	Conclusions	6
References		6

LIST OF ILLUSTRATIONS

	Figure
Turbulence encountered by Hermes aircraft	1
Total numbers of gusts recorded on Hermes, Comet, Viking and Bristol Freighter	2
Number of gusts exceeding different magnitudes per 1000 exceeding 10 ft/sec. E.A.S.	3
10 ft/sec E.A.S. gusts encountered by Comet	4
10 ft/sec E.A.S. gusts encountered by Comet and Viking	5
10 ft/sec E.A.S. gusts encountered by Comet and Hermes	6
Frequency of occurrence of gusts of magnitude greater than 10 ft/sec E.A.S. at different heights	7

1 Introduction

The gust loads on an aircraft are important from the standpoint of both static strength and fatigue. Records of aircraft acceleration in flight are obtained from counting accelerometers which record the number of times various acceleration levels are reached[1,2]. The objective is to record accelerations of the centre of gravity and it is important to be certain how faithfully this is done in reality. The accelerometer is mounted in the fuselage and records the response to a gust with undefined space and time gradients. The record, moreover, relates to the local structure on which the accelerometer is mounted so that even when the position coincides with the centre of gravity of the undistorted aircraft, the records may be influenced by structural deflections under load.

The accelerometer counts are directly applicable only to the particular aircraft and operating conditions under which they are recorded. In order to give the results more general application, it is necessary to estimate the appropriate atmospheric conditions. For this purpose the height and speed of the aircraft are required and these are recorded photographically, together with the counts, at intervals of ten minutes. In the subsequent analysis, the effect of the flexibility of the aircraft is ignored and the recorded acceleration is assumed to be that of the centre of gravity of the aircraft*.

In order to convert the recorded acceleration to gust velocity the method given by Zbrozek[3, 4], is used. To simplify the aerodynamic analysis he assumes a rigid aircraft and ignores the pitching response induced by the gust. The gust velocity is assumed to increase linearly to its maximum value. After conversion of the recorded accelerations to gust velocities by this method, the member of gusts exceeding each magnitude in the required series is calculated.

2 The variation of gust frequency with gust velocity

A typical set of records is given in Ref 5 relating to Hermes aircraft. The original data from which this report has been prepared were obtained from about 2000 hours flying on B.O.A.C. routes. The flying is grouped in altitude bands of 5000 ft and Fig 1 shows miles per gust plotted on a logarithmic scale against gust velocity. The ordinate corresponding to a given gust velocity is the logarithm of the total number of miles flown in the altitude band, divided by the number of times the given gust velocity is equalled or exceeded. It will be seen that the variation of frequency with gust velocity is substantially the same at all altitudes, with perhaps the exception of the highest band which consists of only a small sample. This band is more turbulent than would be expected and shows a slight increase in frequency of the higher velocity gusts. However, in order to estimate the relative gust frequencies it seems reasonable to total the gusts recorded at all altitudes. This has been done for each of the four aircraft for which records are at present available[5, 6, 7, 8]. Data from test flying on the Comet are also included[9]. The graphs of log (number of occurrences) against gust velocity are of approximately the same slope for all the aircraft. The small variation may be attributed to the differences in flexibility of the aircraft, for which no allowance is made.

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* If allowance is made for flexibility in stressing, its effect on both acceleration and stress should be included.

The result of totalling the data from all the four aircraft is given below and shown plotted on Fig 2

Gust Vel. ft/sec	-45	-40	-35	-30	-25	-20	-15	-10	10	15	20	25	30	35
No. of gusts	2	2	8	15	64	259	1192	6665	9878	2022	462	103	26	5

Up to a gust velocity of 30 ft/sec up gusts are more frequent than down gusts in the ratio of about 3 to 2. This may be partly due to manoeuvring accelerations which are superimposed on those produced by gusts, although it is doubtful whether the effect of this can account for all the disparity. At higher gust velocities the down gusts appear to predominate although the numbers are too small for this to be very significant. A possible explanation is that no allowance is made for any changes which might occur in the slope of the lift curve at the high positive incidences involved; when the aircraft is in level flight at a positive incidence, a stalling up-gust is of a lower velocity than a stalling down-gust, and thus errors introduced by assuming a constant slope to the lift curve near the stall have a greater influence on the estimates of the up-gusts.

In the estimation of fatigue damage from gust data it is usual to assume that an up gust is associated with a down gust of equal magnitude, and to take the mean of the numbers of up and down gusts as the number of fatigue loading cycles. For this purpose the numbers of up and down gusts given above are added and an empirical curve fitted. Standardized to give 1000 gusts of 10 ft/sec or greater the formula is:-

$$F = 27,800\ e^{-0.34411v} + 878.2\ e^{-0.20816v}$$

where v is the gust velocity in feet per second and F is the number of gusts equal to or exceeding v ft/sec. The above form of the expression is of use when calculating damage[10]. For calculating frequencies a more convenient form is:-

$$F = 10^{4.4441-0.14945v} + 10^{2.9436-0.09040v}$$

The relation is shown graphically in Fig 3. In most cases, the lowest measured acceleration corresponds to a gust velocity well below 10 ft/sec and usually approaches 5 ft/sec. In this range the frequency distribution shows no abrupt change and accordingly it is thought justifiable to extrapolate the curve to 5 ft/sec. For any given velocity a confidence range can be estimated and that for 95% confidence is shown in the figure. The estimated range makes allowance for the tendency of the gusts to occur near together in regions of turbulence[11]. The frequencies given by the formula for velocities above 35 ft/sec., should be used with caution as the total number of gusts recorded above this value is only 13 and the sampling errors are large. The ringed points on the figure correspond to experimental values. It is misleading, however, to compare their deviations from the fitted curve with the given confidence band as the experimental points are not independent. Apart from the fact that cumulative frequencies are plotted, high or low numbers of gusts tend to occur together for all gust velocities and the experimental points are highly correlated.

A numerical comparison between the observed and calculated frequencies is made in the following table, the empirical formula being factored to fit the observed frequency at 10 ft/sec.

v ft/sec	F Observed	F Calculated
10 or more	16,543	16,543 (fitted)
15 " "	3,214	3,276
20 " "	721	698
25 " "	167	164.3
30 " "	41	43.3
35 " "	13	12.7
40 " "	2	4.0
45 " "	2	1.3

3 Variation of Gust Frequency with Altitude

Having examined the variation of gust frequency with gust velocity it is necessary to examine the variation with altitude. This is done for a gust velocity of 10 ft/sec; the frequency of gusts of any other velocity may then be deduced from the relation given above. When considering the data from this point of view it is important to remember that they do not represent a random sample of atmospheric conditions, but are influenced by any action which the pilot may take to avoid turbulence. This has little effect on the relative frequencies observed at differing gust velocities discussed in para 2, but has a marked effect on the observed variation with altitude. While cruising, the pilot endeavours to avoid turbulence by small changes of both direction and height. On the other hand an aircraft with a high cruising altitude normally climbs to, and descends from, this altitude through any turbulence it may encounter, without any avoiding action being taken.

(i) Fig 4 shows data for 10 ft/sec gusts for Comet aircraft[6]. The normal cruising height is about 34,000 ft and it may be assumed that the records up to at least 25,000 ft are representative of average atmospheric conditions. Up to this altitude the relation between log (miles per gust) and altitude shows no significant departure from linearity[11].

(ii) A comparison is now made with data from an aircraft cruising at a much lower altitude. Fig 5 shows observations for Comet plotted with observations for Viking aircraft[7]. The Viking observations have been classified as climb, cruise or descent depending on the difference in the recorded heights at the beginning and end of each ten-minute interval. The curves for the Viking lie almost wholly above that for the Comet, the exception being in the lowest altitude band, and show that during cruise, by selecting a favourable altitude and course, an average improvement corresponding to a factor of about 3 can be achieved. The pronounced maximum in the cruise curve at the normal cruising altitude is a result of selecting a favourable altitude. The aircraft climbs to its normal cruising altitude and stays there unless turbulence is encountered, in which case it climbs in an attempt to find smoother conditions. Consequently flying above the normal cruising altitude only occurs in conditions which are worse than average. The curve for the Viking climb and descent shows similar tendencies, indicating that even under these conditions the pilot's avoiding action has a considerable effect, and confirming that climbing above the normal cruising altitude only takes place in adverse conditions.

(iii) The data for the Hermes[5] have not been classified into climb, cruise and descent, but it can be assumed that the majority of flying above 8,000 ft is under cruising conditions. Fig 6 shows a comparison between the Comet and Hermes. A similar trend to that observed in the case of the Viking is found, although to a lesser extent. The indications are that the pilot's avoiding action becomes less effective as the altitude increases. If this is the case the change in slope shown by the Comet curve at about 25,000 ft may not in fact be due to the pilot's avoiding action but may represent a real change in atmospheric trend. Further light on this question will be obtained as records from aircraft cruising at greater altitudes become available.

Estimates of the average gust frequency at various heights based on all the relevant data are given in Fig 7, where a confidence range of 95% is shown about each experimental point, allowance being made for the tendency of the gusts to occur in groups. The value shown for the lowest altitude of 1050 ft is the mean of the Comet, Hermes and Viking, climb, cruise and descent. With the exception of the Comet these show little significant difference. The value for the Comet is somewhat high but is, however, based on a very small sample, (only 860 miles). Apart from this altitude band, the remainder of the main curve follows values obtained from the Comet data.

The value for the cruise of each aircraft has been obtained by taking the average of the highest three or four altitude bands. This is thought to give a more representative figure than that for the normal cruising altitude only, which is obtained under selectively good conditions. The improvement achieved under cruising conditions by the pilot's avoiding action is indicated by the dashed line in Fig 7.

4 Conclusions

The present information on the variation of gust frequency with gust velocity and altitude is conveniently summarized in Figs 3 and 7. These figures give a representation of atmospheric turbulence which may be used for the estimation of aircraft fatigue damage resulting from gust loads.

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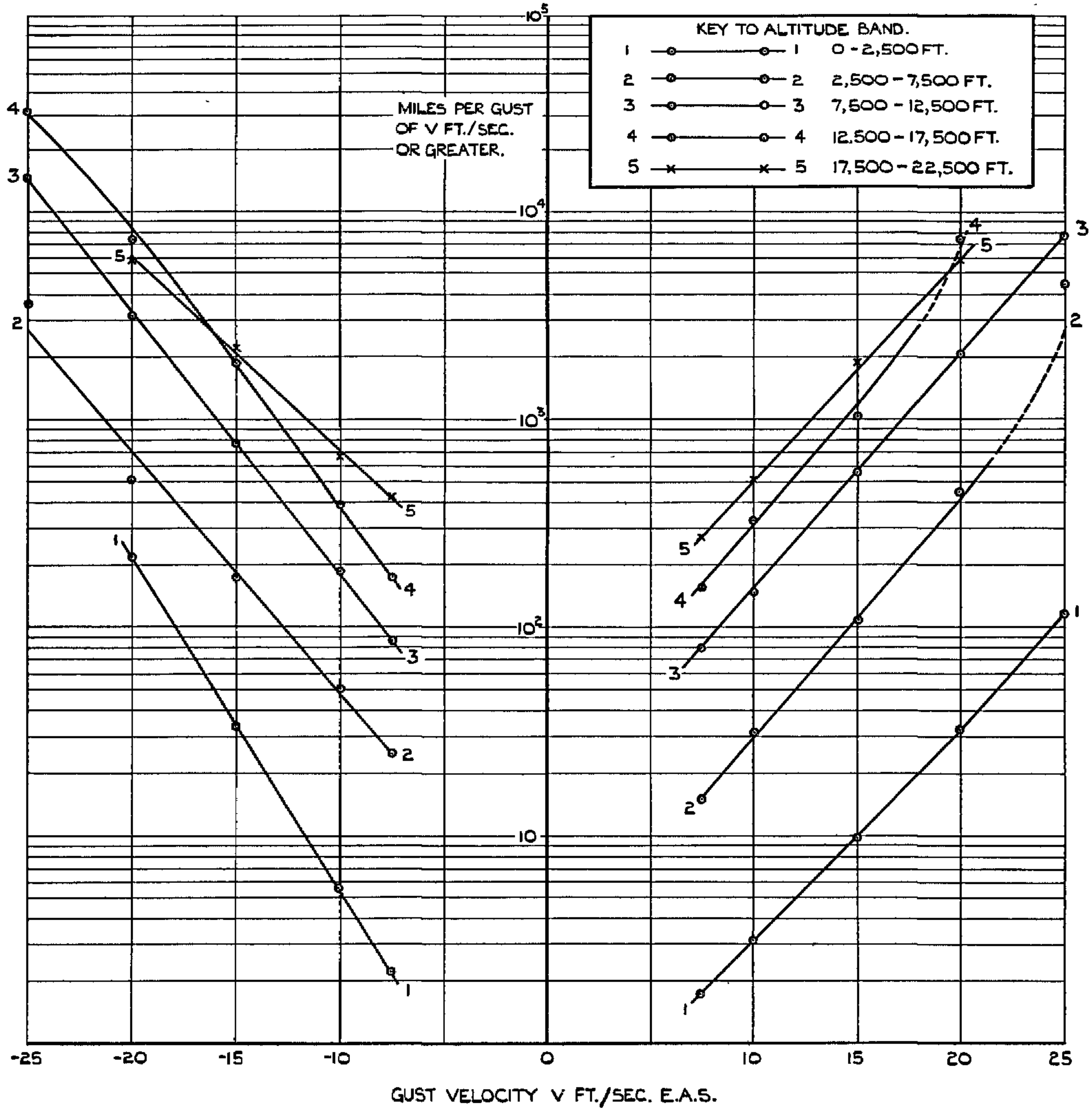


FIG. 1. TURBULENCE ENCOUNTERED BY HERMES AIRCRAFT.

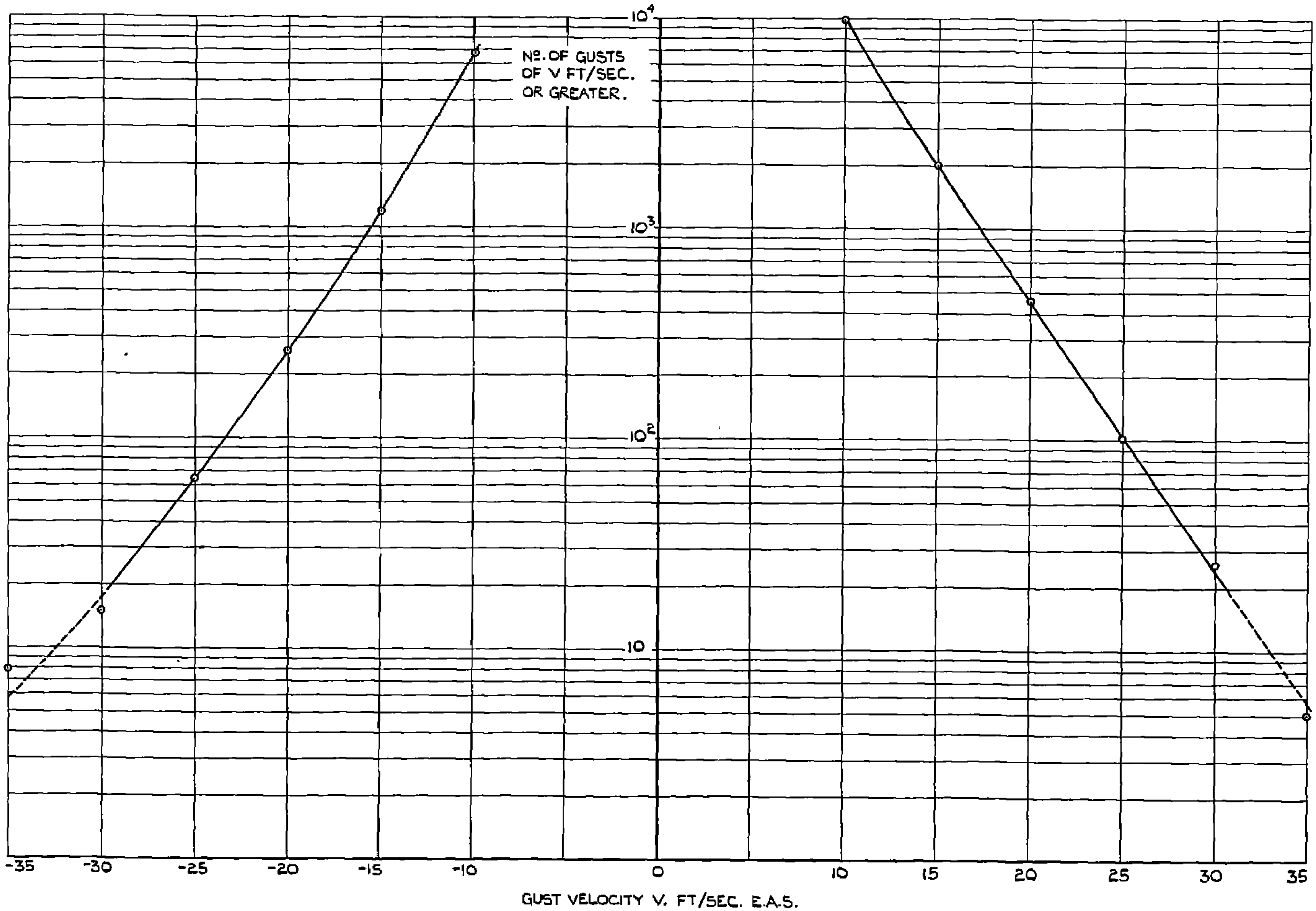


FIG. 2. TOTAL NUMBERS OF GUSTS RECORDED ON HERMES, COMET, VIKING AND BRISTOL FREIGHTER.

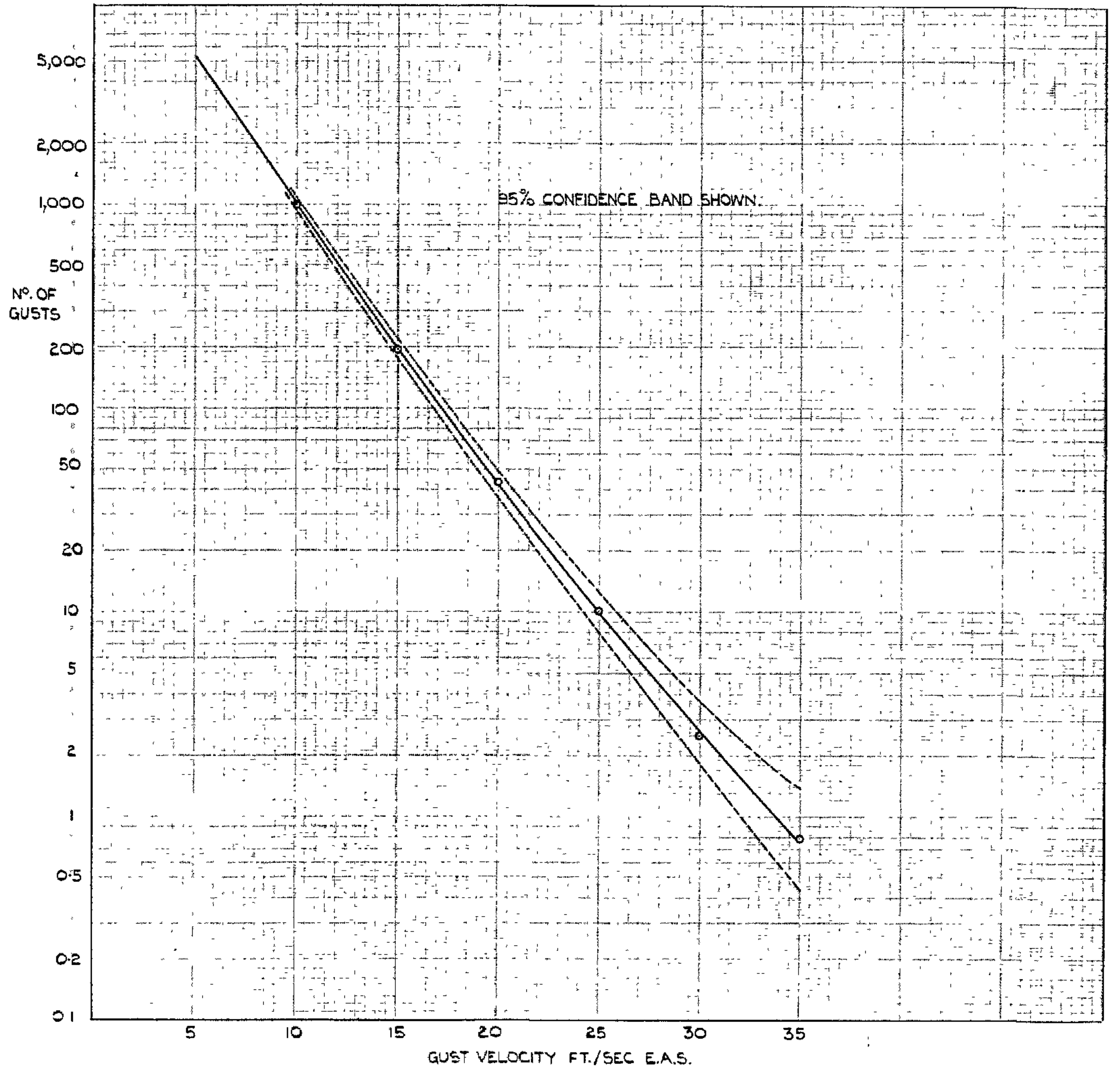


FIG. 3. NUMBER OF GUSTS EXCEEDING DIFFERENT MAGNITUDES PER THOUSAND EXCEEDING 10 FT./SEC. E.A.S.

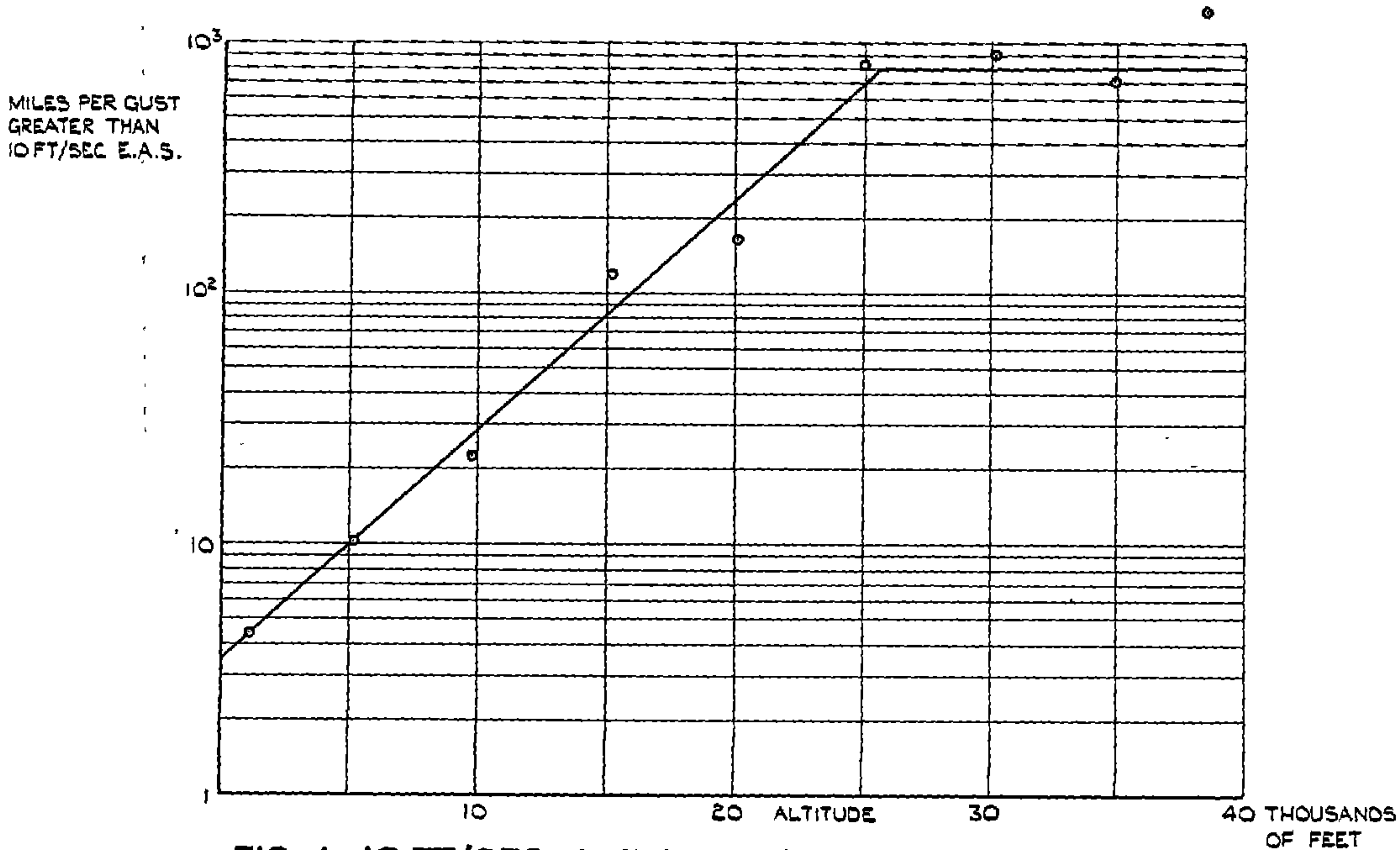


FIG. 4. 10 FT/SEC. GUSTS ENCOUNTERED BY COMET.

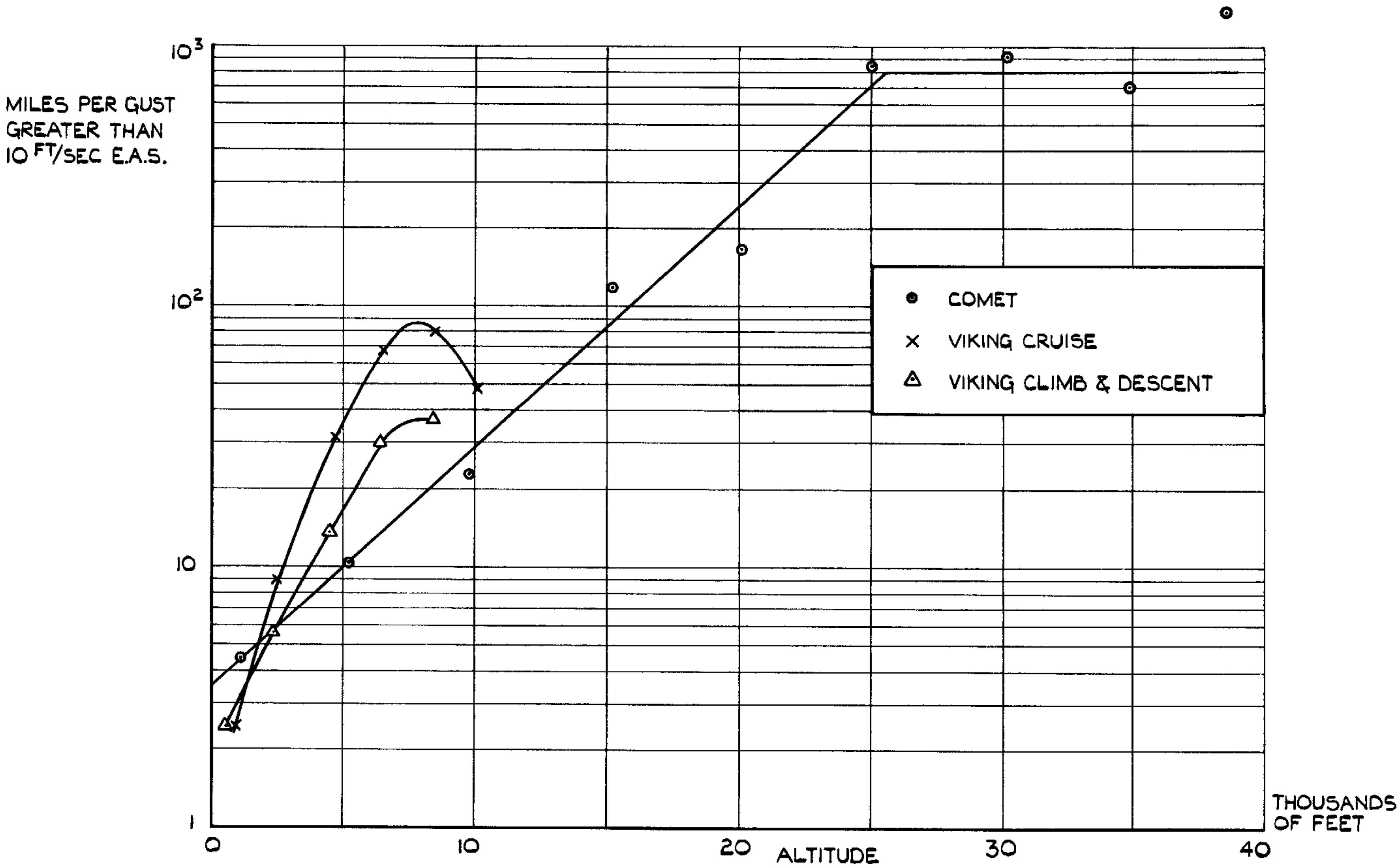


FIG.5. 10 FT/SEC. GUSTS ENCOUNTERED BY COMET & VIKING.

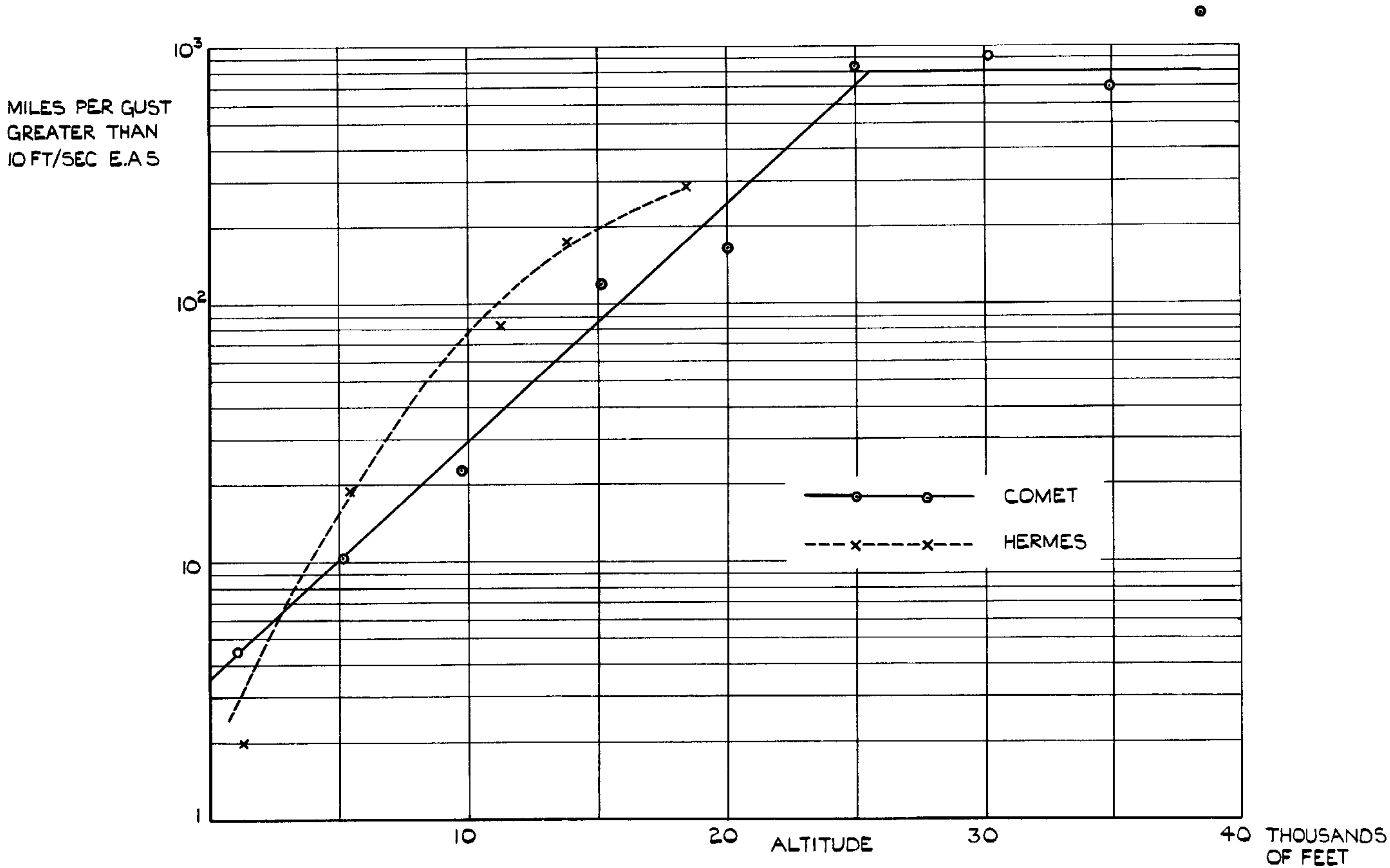
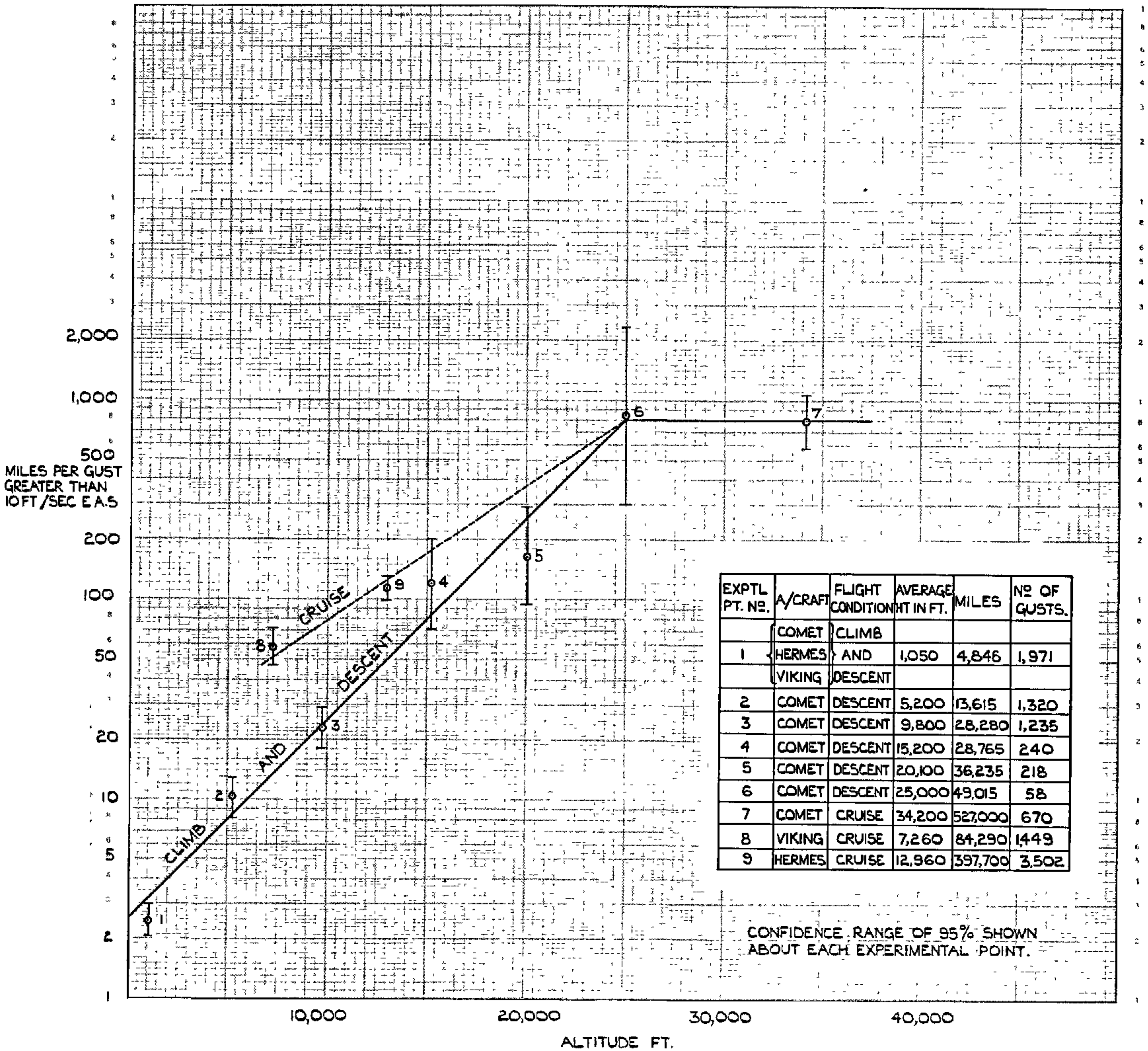


FIG. 6. 10 FT/SEC. GUSTS ENCOUNTERED BY COMET & HERMES.



EXPTL PT. Nº.	A/CRAFT	FLIGHT CONDITION	AVERAGE HT IN FT.	MILES	Nº OF GUSTS.
1	COMET HERMES VIKING	CLIMB AND DESCENT	1,050	4,846	1,971
2	COMET	DESCENT	5,200	13,615	1,320
3	COMET	DESCENT	9,800	28,280	1,235
4	COMET	DESCENT	15,200	28,765	240
5	COMET	DESCENT	20,100	36,235	218
6	COMET	DESCENT	25,000	49,015	58
7	COMET	CRUISE	34,200	527,000	670
8	VIKING	CRUISE	7,260	84,290	1449
9	HERMES	CRUISE	12,960	397,700	3,502

FIG.7. FREQUENCY OF OCCURRENCE OF GUSTS OF MAGNITUDE GREATER THAN 10 FT./SEC. E.A.S. AT DIFFERENT HEIGHTS.

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