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Gusts at Low Altitude in North Africa

by

N. I. Bullen, B.Sc.

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GUSTS AT LOW ALTITUDE IN NORTH AFRICA

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SUMMARY

Flights have been made in North Africa over a period of one year in order to investigate low altitude turbulence. Discrete gust analysis is used and gust spectra are given covering the year's flights for different times of day and over different types of terrain.

The variation in intensity throughout the year and the variation with height up to 600 feet are examined.

The effect of compressibility on the gust alleviation factors for speeds up to a Mach number of 0.6 is shown to be small.

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1 INTRODUCTION

From August 1959 to July 1960 an extensive investigation on low altitude turbulence was made in North Africa, Canberra aircraft making daily flights over different types of terrain. The main object of the experiment is to examine the influence of various factors on the intensity of turbulence. Such factors include type of terrain, altitude, time of day and time of year. An attempt is also being made to correlate turbulence levels with meteorological factors such as wind speed, wind shear, temperature and lapse rate. The effects of turbulence and heat on the performance of the crew are also being investigated by the Institute of Aviation Medicine.

The present paper is confined to consideration of the variations observed with changes of terrain, altitude, time of day and time of year. The detailed examination of the influence of the various meteorological factors will form the basis of a further paper.

In view of the large number of observations made, it was essential that the data collection and processing should be as automatic as possible and for this reason the counting accelerometer, giving records of normal accelerations, was chosen. A detailed description of this instrument is given in Section 4.

These observations were supplemented by flights, on a few occasions, of a specially instrumented Canberra making measurements of turbulence by means of a nose probe. From these observations turbulence spectra are being estimated, and it is hoped to relate spectral shape with the frequency distribution of gusts.

2 ROUTES

The routes over which flying took place are shown in Fig.1. The bulk of the flying was done on the circuit to the west of El Adem. Flying the circuit clockwise, the first leg represents a fairly flat desert terrain. The next leg is described in what follows as hilly desert, although this term is perhaps a little misleading. The region was originally a plateau from which valleys and crevices have been eroded, so that the highest ground is more or less on the same level. However, it provides a rougher terrain to contrast with the flat desert. Its average height above sea level is about 1500 feet. The remainder of the circuit is over the sea except for the short run-in to El Adem over the land, which does not contribute to the data.

The route to the south of El Adem, referred to as the Giarabub circuit, is of flat desert similar to the first leg of the El Adem route. It is, however, further from the coast and it is thought that it would be less influenced by any sea breeze effect, particularly on the most southerly leg.

The routes based on Idris represent coastal strips and cultivated and wooded regions. The crops consist mainly of dates and citrus fruits, and the vegetation provides a contrast to the bare desert.

3 FLYING SCHEDULE

The original flying schedule is given in Table 1. On the El Adem circuit an early morning sortie at about 06.15 G.M.T. (07.45 Local Solar Time) was flown daily except for week-ends. Turbulence due to convective activity is small at this time, except perhaps in midsummer, and most of the gusts are wind excited. The midday sortie was aimed at maximum convective activity and was timed for 11.15 G.M.T. (12.45 Local Solar Time). This was also a daily flight. In addition, occasional sorties were flown at other times of the day to give a wider coverage. These were mainly flown in the afternoon.

Beginning in November, additional flights were made towards Giarabub and were flown on average three times a week. Idris was visited at about fortnightly intervals to make flights over the coastal and cultivated types of terrain.

The normal height for flying was at 200 feet, unless a stacked sortie was being flown by three aircraft, in which case the heights were 200, 400 and 600 feet over the land and 100, 200 and 400 feet over the sea. It was intended to fly a stacked sortie at midday once a week, but unserviceability and instrument faults reduced this to about once a fortnight.

For the first two months the flying speed was 250 knots, but this was then increased to 300 knots for the remainder of the trials, except for a few flights at 400 knots made primarily to examine the effects of even more severe conditions on the crew.

4 AIRCRAFT AND INSTRUMENTATION

The aircraft used were 6 Canberra Mk. B2 with an average take-off weight of 33,000 lbs. Other relevant particulars are:-

Wing span	- 64 feet
Mean chord	- 15.0 feet
Gross wing area	- 960 sq feet
Aspect ratio	- 4.25
Slope of lift curve	- 3.60 per radian

To record the normal accelerations experienced by the aircraft an R.A.E. Compound Counting Accelerometer Mk.5 was installed near the aircraft centre of gravity. The accelerometer has a natural frequency of 7 c/s and the response falls to 70% at 11 c/s. The response curve is as given in Ref.1. The recording camera takes a picture at 1 minute intervals and records the counter readings, the height and speed of the aircraft, and the time.

In order to register a count at a particular level the acceleration must pass that level and then return a certain distance towards the 1g level corresponding to steady flight. These distances are given in Table 2 and correspond roughly to half the return distance.

These characteristics have been decided with the estimation of fatigue lives in mind, and are intended to avoid counts being recorded by small oscillations, caused by aircraft flexibility, about a peak value. Investigations have shown that for all the larger excursions the acceleration almost always returns to the zero line and beyond before producing a further peak value*. The overall effect of the instrument is thus to approximate to the cumulative distribution of peak values which would be obtained in the same circumstances from a rigid aircraft but having a response increased by the dynamic overshoot factor. In the subsequent analysis, the counting accelerometer records are assumed to give the cumulative distribution of peak values.

On two of the six aircraft a thermometer (Meteorological Office aircraft resistance thermometer) was fitted on the nose for determining temperatures and lapse rate during flight. For this purpose climbs to a thousand feet were made at the turning points of the circuit.

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* I am indebted to Mr. J. R. Sturgeon of Structures Department, R.A.E. for this information.

5 METEOROLOGICAL INFORMATION

The main meteorological information was obtained from the El Adem Station and consisted of

Surface wind speed and direction
Screen temperature
Relative humidity
Solar radiation
Cloud type and amount
Visibility
Upper winds to 1500 feet in 500 feet layers
Temperatures at 500 and 1000 feet.

Similar information was available from Idris for the Idris flights.

In addition, stations at Cyrene, Derna, Benina and Tobruk, Zuara and Misurata for the Idris flights, provided the following

Surface wind speed and direction
Screen temperature
Relative humidity
Cloud type and amount
Visibility.

The aircraft crew report included cloud type and amount, visibility, and temperature information when the aircraft carried a thermometer.

6 CONVERSION OF ACCELERATIONS TO GUST VELOCITIES

The recorded normal accelerations are converted to gust velocities by the usual discrete gust procedure described by Zbrozek[2]. Fig.2 shows the gust alleviation factors determined by this method and makes comparison with the standard curve given by Pratt and Walker[3] and which is used for discrete gust calculations in the U.S.A. The aircraft is assumed rigid and pitching is neglected. Compressibility effects are also neglected in the analysis A few flights at 400 knots are examined to check the effects of compressibility rather than pooling this information with the main body of data.

Fig.3 shows the kind of information obtained from one leg of a flight; it is from the flat desert leg on the El Adem circuit, midday on 24th August 1959. The frequencies are plotted on a logarithmic scale.

It will be seen that there are slightly more up gusts than down gusts recorded. This may be a real effect, but it has been suggested that the bias is caused by very small positive manoeuvre accelerations. This bias is observed on all the records and usually corresponds to a shift of axis of about 0.05g or less.

When fitting a curve to the gust distribution the geometric mean of the numbers of up and down gusts is taken, but where it is merely required to give a figure for the number of gusts per mile at some level of gust velocity, the arithmetic mean is considered adequate.

The number of gusts of some specified magnitude per mile is often used in making comparisons between intensities of turbulence and is indeed the only practicable way when the turbulence is light and the only gusts counted are at the lowest level.

In general, however, the spread of the distribution indicates the severity of the turbulence. By extrapolating the curve to the axis, the intercept gives a frequency parameter which corresponds to the number of positive zero crossings per mile, if this parameter is independent of intensity. For a stationary random Gaussian process the peak values have a Rayleigh distribution and the mean square of the peak values is twice the mean square of the original variable. Even if the mean square of the original variable itself varies, this result still holds, providing the number of zero crossings per unit distance is constant. This provides a convenient method of estimating root-mean-square gust velocity from the distribution of peak values.

An idea of the homogeneity of the turbulence can be obtained by looking at the curvature of the distribution as plotted on a log scale. For homogeneous turbulence we shall have a Rayleigh distribution of peaks but as the intensity becomes more variable the downward curvature decreases. By the time the root-mean-square gust velocity itself has a Gaussian distribution the peak distribution has become exponential and plots as a straight line on the log scale. Further variability in the intensity produces upward curvature.

Fig.4 shows the Rayleigh and exponential distributions having the same root-mean-square and number of zero crossings as the curve derived from the observations of Fig.3, but with the up and down gusts combined as explained above.

7 EXAMINATION OF RESULTS

7.1 Main gust spectra for the year's flying

The bulk of the flying was done on the El Adem route. To form a broad basis for comparison these data are first of all classified according to type of terrain and time of day and the results summed for all times of the year.

The three types of terrain on the El Adem circuit are

(a) Flat desert,
(b) hilly desert, and
(c) sea.

The times of day are classified as follows:-

Morning:	05.00 - 06.55 G.M.T.
Midday:	11.00 - 12.55 G.M.T.
Afternoon:	13.00 G.M.T. onwards.

A few early morning and mid-morning flights are outside these time limits and are therefore excluded from this initial survey, as are flights at heights other than 200 feet. The flights at 400 knots are also excluded. We thus have a 3 x 3 classification covering all times of the year. The gust spectra for these cases are shown on Figs.5-10. Figs.5-7 give a comparison of the effects of terrain and the curves are replotted in Figs.8-10, to compare times of day.

Fig.5

On the morning flights the turbulence is mainly wind excited. The two smooth surfaces - the flat desert and sea, give quite similar distributions, while the hilly desert has significantly more gusts.

Fig.6

At midday convective activity predominates; the hilly desert is only slightly more severe than the flat desert but both have far more turbulence than over the sea.

Fig.7

In the afternoon the convective activity decreases but the gust spectra show a rather curious tendency to grow "tails", indicating an occasional big gust. However, the actual numbers involved here are small and may not be very significant.

Figs.8 and 9

A comparison of times of day brings out the large influence of convection over the land. Both flat and hilly desert show similar trends.

Fig.10

It is to be expected that the diurnal variation over the sea is much less, but the extent to which the spectra for different times of the day agree is perhaps rather surprising.

As explained previously an estimate of the root-mean-square gust velocity can be obtained by using the fact that the mean square gust velocity is equal to half the mean square of the peak distribution, subject to certain qualifications. It should also be remembered that the gust velocities are obtained using a discrete gust alleviation factor. However, with these reservations, the root-mean-square gust velocities at midday over the flat and hilly desert for the one year period are 3.58 ft/sec and 4.08 ft/sec respectively.

7.2 Giarabub sorties

The reason for including the Giarabub route was to fly over desert terrain further from the coast than on the El Adem route. It is of interest to see if there is any significant difference in the results. If so there should be a consistent trend from the El Adem route to the two north-south Giarabub legs and then to the most southerly leg. The mean distances from the coast are 30, 80 and 140 miles.

In fact very little difference is observed. At midday in winter about 20% fewer gusts are found on the El Adem leg than on the Giarabub legs, which show little difference between themselves. There is also some slight indication that the turbulence persists in the afternoon a little longer on the El Adem leg, about 20% more gusts being observed than on the Giarabub route. These small differences may not have much significance and in much of the subsequent analysis the Giarabub data have been pooled with the El Adem flat desert data.

7.3 Idris sorties

The gust distributions for the Idris flights are shown in Figs.11 and 12. The turbulence over the cultivated terrain (Fig.11) shows much the same characteristics as that over the flat desert, the only difference being that the turbulence in the afternoon on the Idris flights is somewhat more severe. An explanation of this may be that the average times for the afternoon flights were 15.05 G.M.T. at Idris and 15.10 G.M.T. at El Adem. As the Idris route is about 10 degrees west of the El Adem route, the flights are 45 minutes earlier by solar time and so nearer midday.

The spectra for the coastal routes (Fig.12) appear to be merely a mixture of the land and sea spectra in roughly equal proportions and with no other characteristics of note.

7.4 Yearly variation

In order to show the variation in turbulence throughout the year the number of gusts of magnitude of 5 ft/sec or greater, per mile is taken as a parameter. (For this purpose the up and down gusts are added.)

Strictly speaking, to define the turbulence more exactly an intensity parameter such as a root-mean-square gust velocity is also required. However, it is not thought necessary to complicate matters by introducing such a parameter at this stage as there is a fairly close correlation between the gust frequency and the intensity of turbulence, particularly when the turbulence is severe enough to persist throughout the observing period.

The most striking variation occurs in the midday flying over land. Figs.13 and 14 give the curves for the flat and hilly desert terrains and show the expected summer maximum. There is little difference between the two; the hilly desert has slightly more gusts but as the wind is presumably more of a factor the points show somewhat more scatter.

The curves for morning flying (Figs.15 and 16) over hilly and flat desert are also very much alike, although in this case the numbers of gusts over the hilly route are about twice those for the flat desert. Here the time of sunrise is an important factor. There is little or no convection in winter, but in the summer convective activity is already beginning to build up.

The afternoon flights over land (Figs.17 and 18) show rather a large scatter, with less trend with time of year and no particular features of note.

The turbulence over the sea is almost always slight or negligible. As there is little variation with time of day, observations from flights at all times have been added to examine the variation throughout the year (Fig.19). What turbulence there is tends to be a maximum in winter.

While no extensive analysis of the effects of the meteorological factors has yet been made, it is of interest at this stage to look at the relationship between the turbulence experienced over the flat desert at midday and the solar radiation. For this purpose mean square gust velocities are estimated for each month for midday flights over the flat desert and compared with the midday monthly averages for solar radiation. The result is shown in Fig.20, giving excellent agreement. Fig.21 shows the same data with mean square gust velocity plotted against solar radiation.

7.5 Variation of gust frequency with altitude

To investigate the variation of gust frequency with altitude three aircraft were flown at different heights simultaneously so that direct comparisons were obtained. These are grouped according to time of year and the results for flights over the land are shown in Figs.22 and 23.

Except during the winter the observations confirm a small but marked decrease in gust frequency with increasing altitude. The winter results do not follow the same pattern but the observations at 600 feet are from only four flights and may not give a very reliable value.

The variation with height over the sea is more irregular and as the turbulence is in any case light, no reliable inferences can be drawn. The actual values of the frequencies of gusts of 5 ft/sec or greater are given in Table 3.

7.6 Flights at 400 knots

The data from the flights at 400 knots are processed by the same method as those from lower speeds and compressibility effects are neglected in the analysis. The magnitude of these effects is indicated by a comparison between the two sets of data. As the turbulence over the flat desert is the most homogeneous and most consistent from day to day, the flights at 400 knots over this region are compared with flights at 300 knots over the same region and for the same period. The gust spectra are shown in Fig.24, the main difference being in the frequency parameter while the root-mean-square values correspond closely. In fact the differences are no more than are expected to be produced by sampling errors and the results confirm that up to a Mach number of 0.6 compressibility effects can be neglected in discrete gust calculations for this aircraft.

8 CONCLUSIONS

This paper consists mainly of the factual results of the investigation and these provide valuable information on the turbulence encountered by low flying aircraft operating in sub-tropical regions.

The results confirm the predominating influence of convection on the intensity of turbulence over the land and the quantitative relationship obtained between solar radiation and mean square gust velocity over the flat desert is most encouraging.

The other major factors are likely to be wind speed and terrain roughness and the influence of these can be seen in the difference between the turbulence over flat and hilly desert.

Over the sea the turbulence was slight throughout the observing period of one year and in contrast to the land the intensity was a maximum in winter.

The consistency, under similar conditions, of the observed numbers of gusts encourages the view that a wider application of the results, taking into account all the relevant meteorological and topographical factors, may be possible. However, it will be wise to await the full assessment of the data before reaching any final conclusions.

LIST OF REFERENCES

Ref. No.	Author	Title, etc.
1	Taylor, J.	Design and use of counting accelerometers R & M 2812. June, 1950.
2	Zbrozek, J.K.	Gust alleviation factor. R & M 2970. August, 1953.
3	Pratt, K.G. Walker, W.G.	A revised gust-load formula and re-evaluation of V-G data taken on Civil Transport Airplanes from 1933-1950. NACA Report 1206. 1954.

TABLE 1 - Original flying schedule

Route	How often flown	Approx. take-off time - G.M.T.	Speed I.A.S.	Height		No. of sorties per week	Remarks
				Land	Sea		
El Adem	Twice daily for 3 days a week	5.15 and 11.15 hours	250 kts	200'	200'	6	
El Adem	4 times daily for 2 days a week	5.15, 11.15 hrs plus 2 sorties at night, dawn or other times of day	250 kts	200'	200'	8	
El Adem	Once on 1 day a week	11.15 hours	250 kts	200' 400' 600'	100' 200' 400'	2	3 aircraft to fly at 3 min. intervals at different heights. One a/c may be making the standard daily flight
Idris	2 days a fortnight	5.15 and 11.15 hours	250 kts	200'	200'	2	

Total sorties per week 18

TABLE 2

Accelerometer characteristics

Acceleration movement "g"	Return distance "g"
0.2	0.2
0.3	0.3
0.4	0.3
0.6	0.4
0.8	0.5
1.0	0.6
1.2	0.6
1.4	0.6
1.6	0.6

TABLE 3

Frequency of gusts of 5 ft/sec or greater over the sea at different altitudes

Height (ft)	August Sept. Oct.	Nov. Dec. Jan.	Feb. March April	May June July
100	0.565	1.277	0.698	0.319
200	0.299	0.661	0.850	0.259
400	0.369	0.372	0.957	0.456

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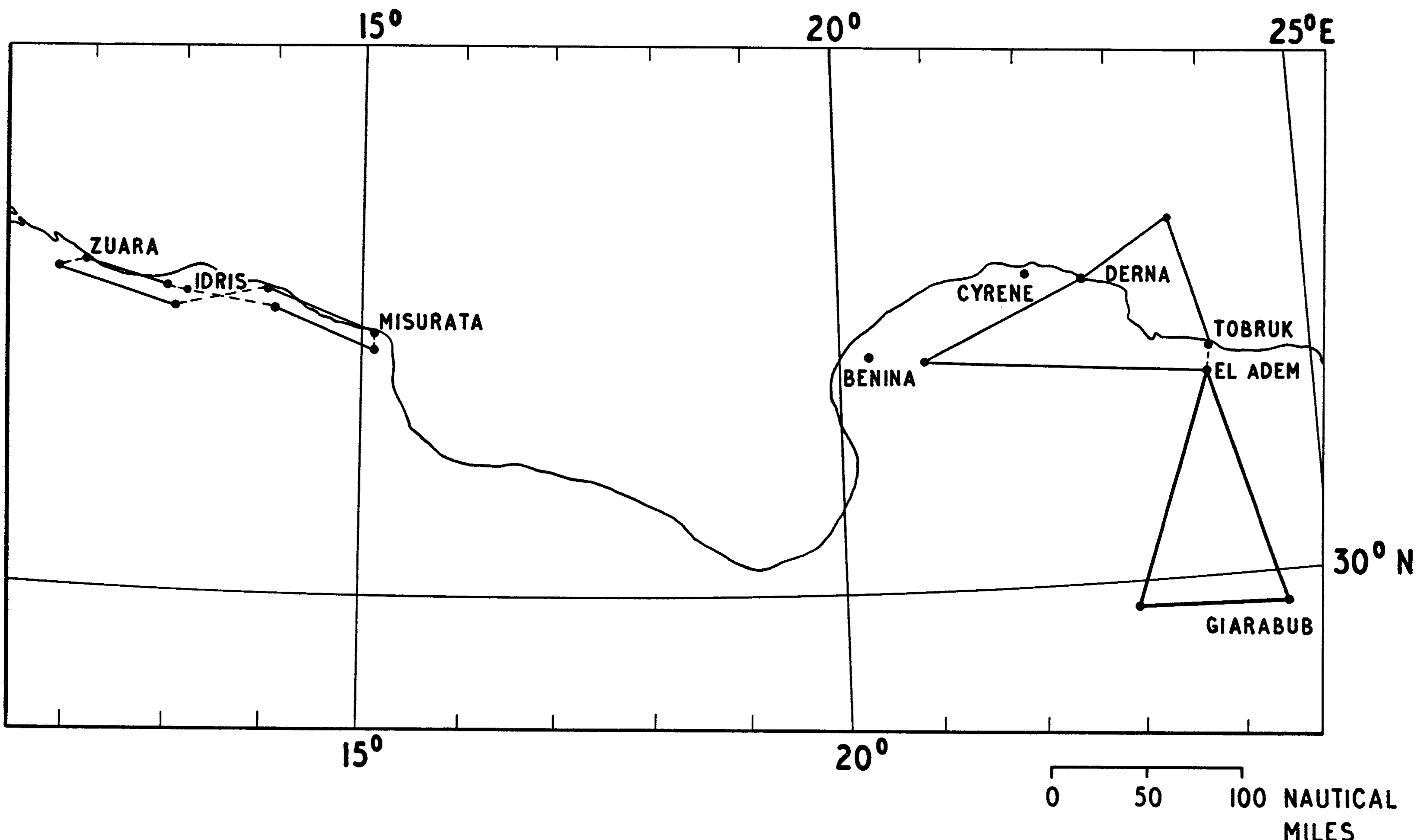

FIG. I. MAP OF ROUTES.

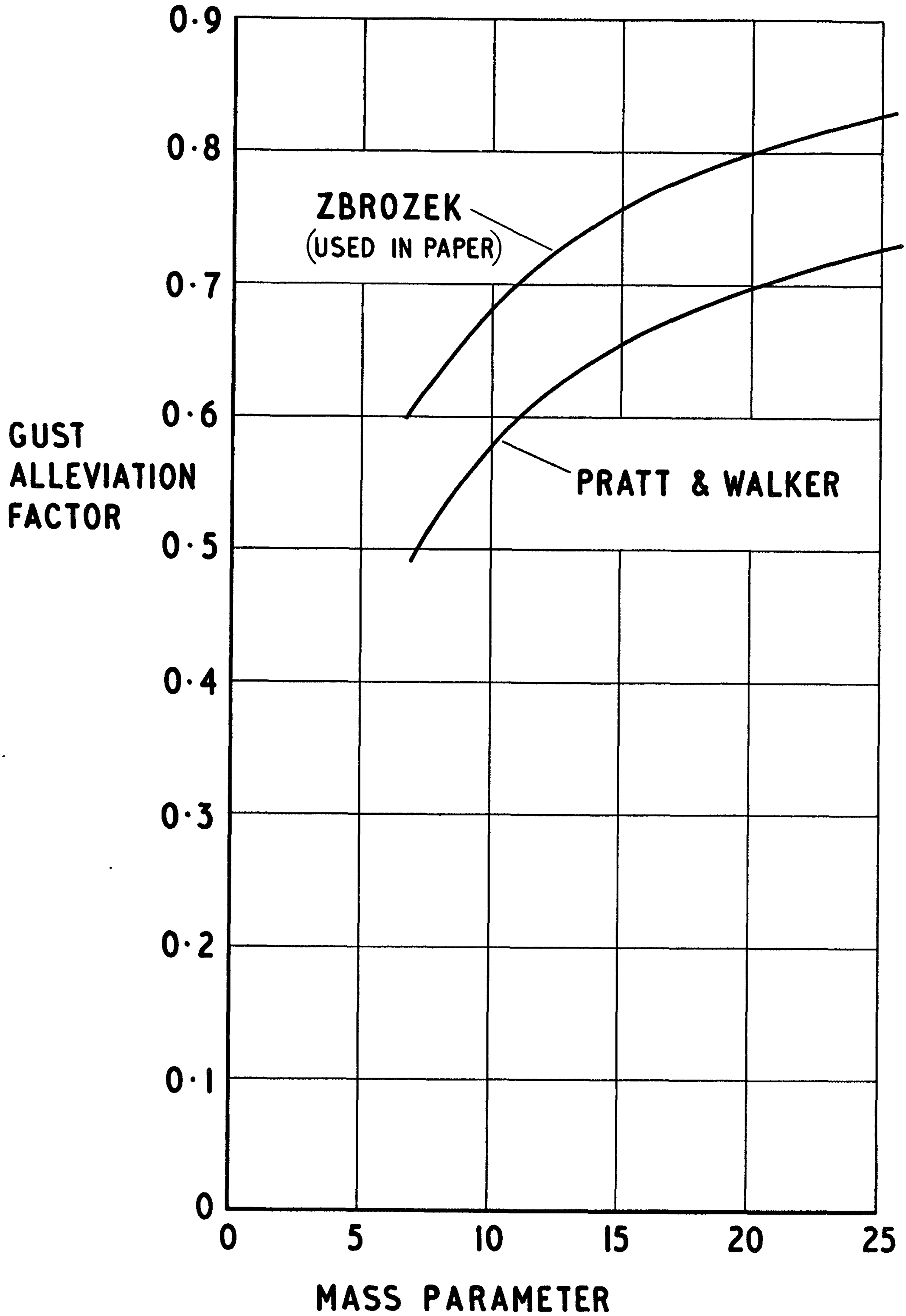

FIG. 2. GUST ALLEVIATION FACTORS FOR CANBERRA B2.

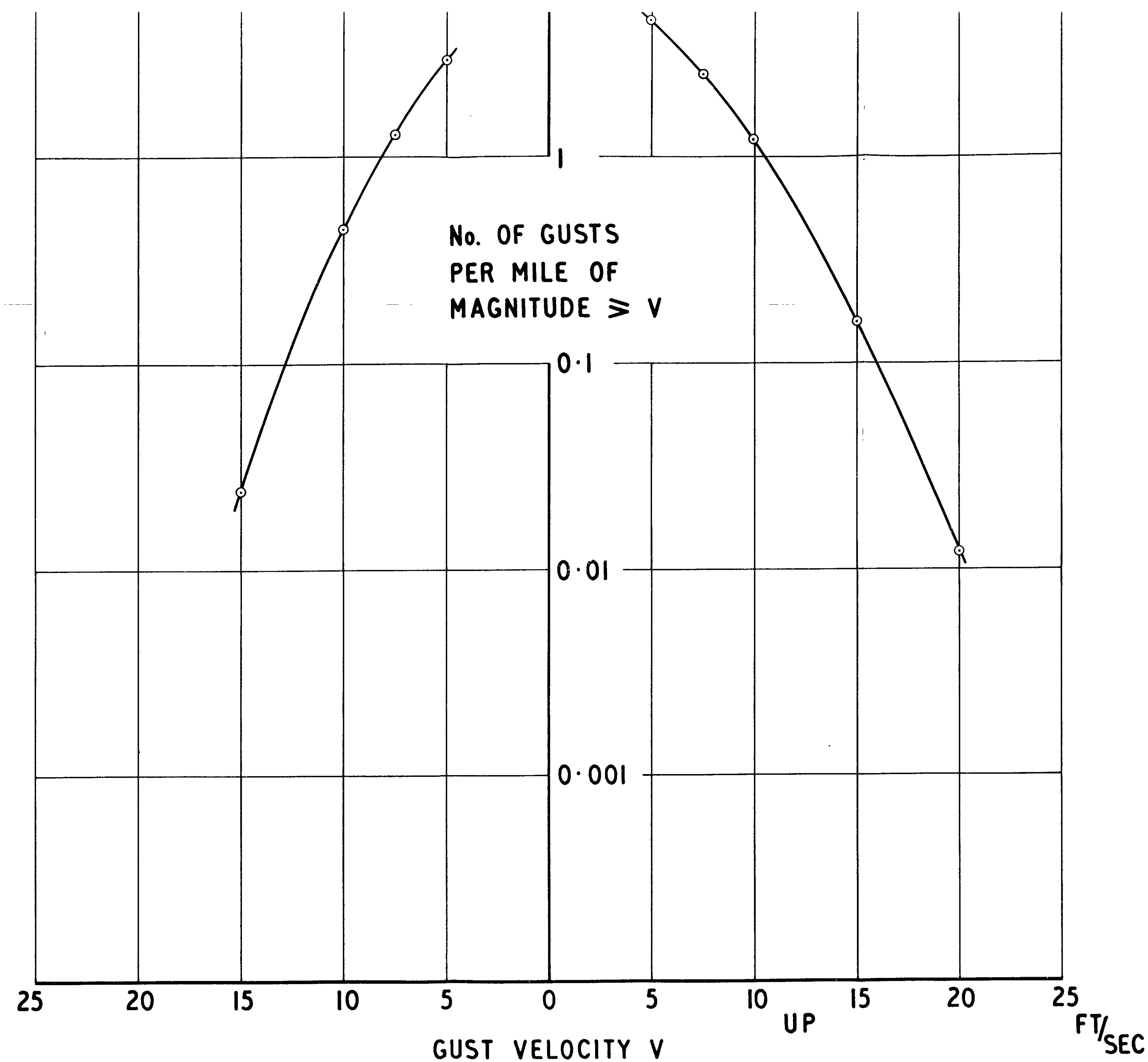

FIG. 3. TYPICAL GUST DISTRIBUTION FROM SINGLE LEG OVER FLAT DESERT MIDDAY. 24TH AUGUST 1959.

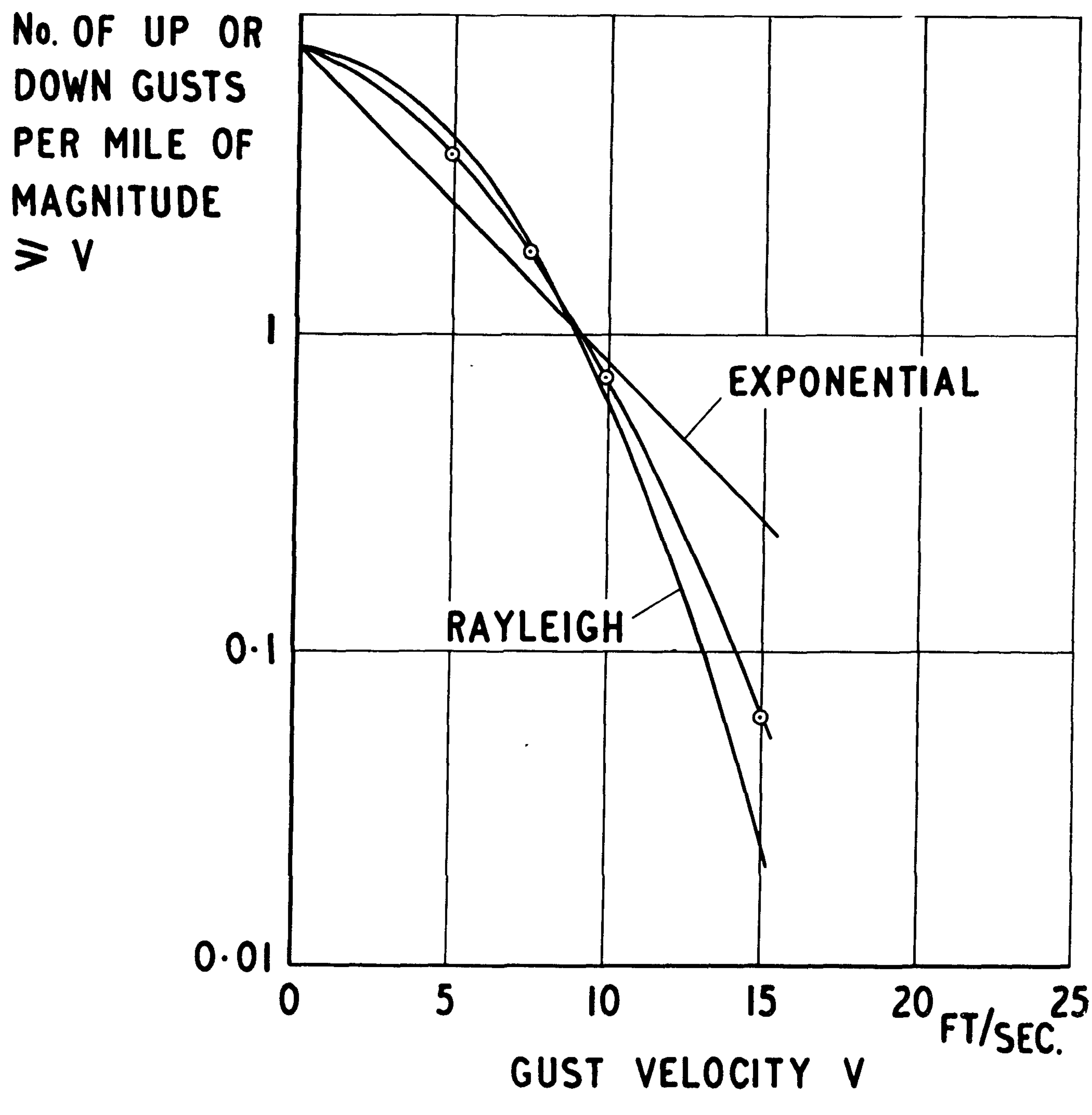

FIG. 4. COMPARISON OF TYPICAL GUST DISTRIBUTION WITH EXPONENTIAL & RAYLEIGH DISTRIBUTIONS.

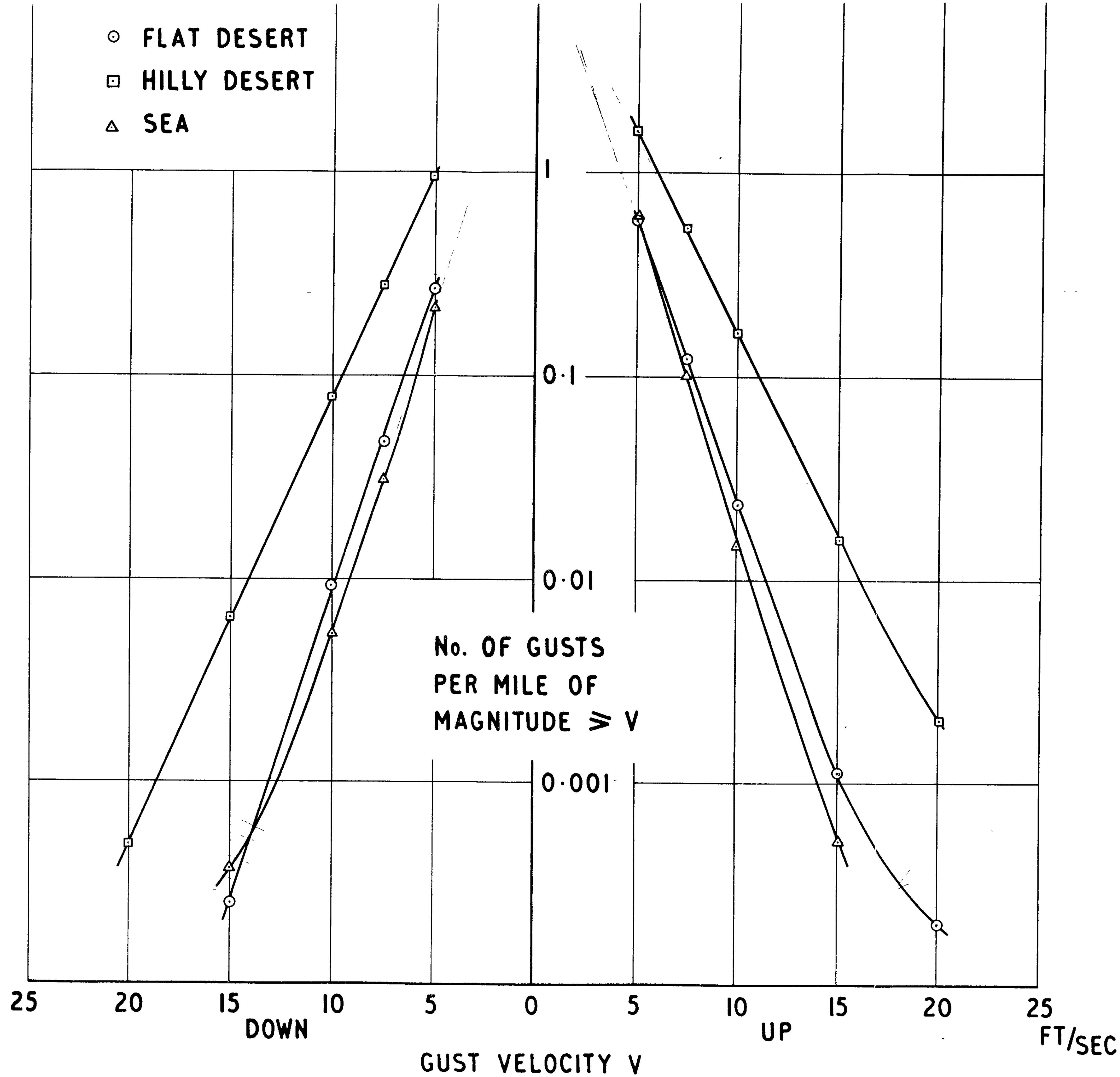

FIG 5 GUST SPECTRA FOR MORNING FLIGHTS - ALL THE YEAR

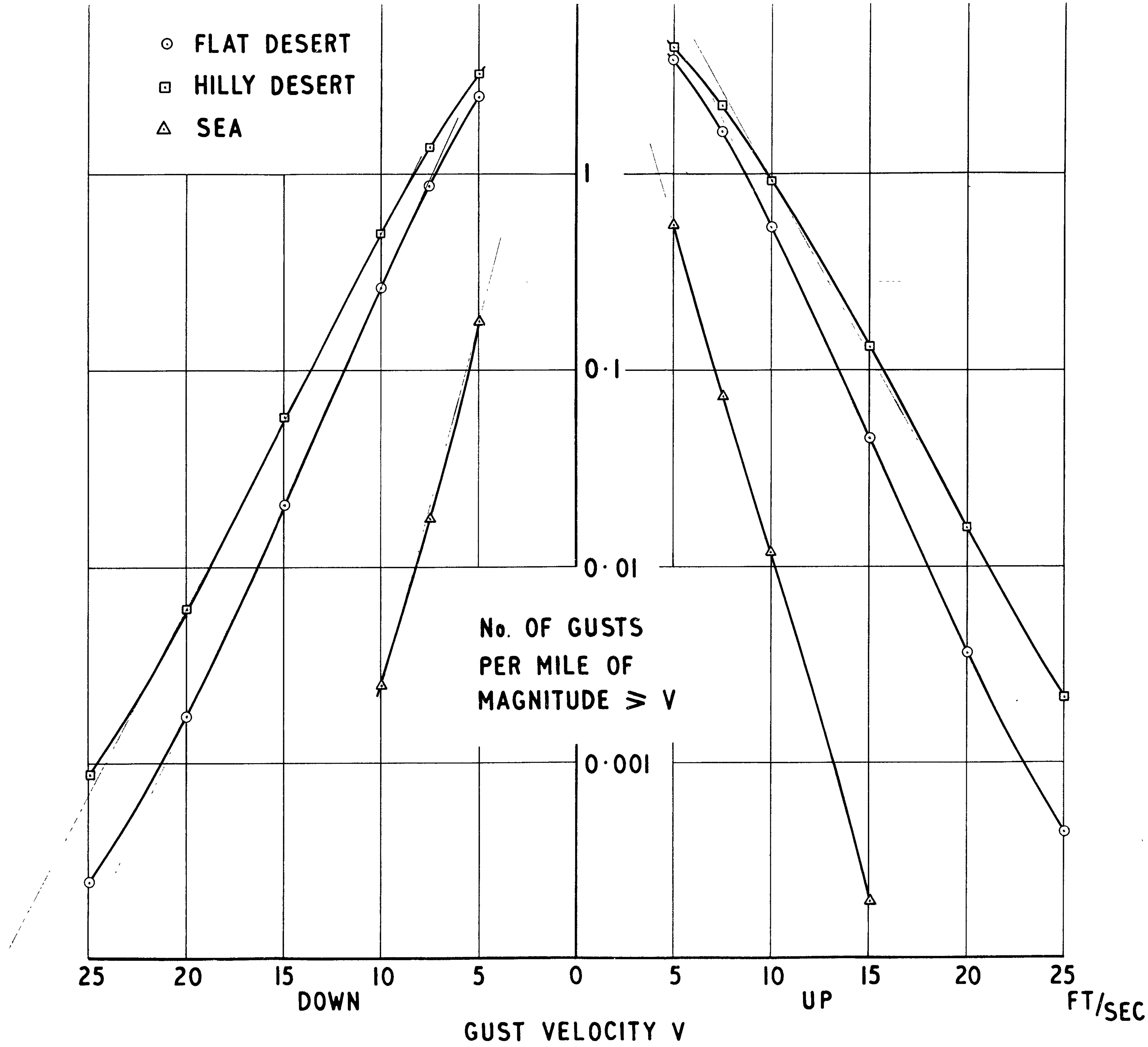

FIG. 6 GUST SPECTRA FOR MIDDAY FLIGHTS - ALL THE YEAR

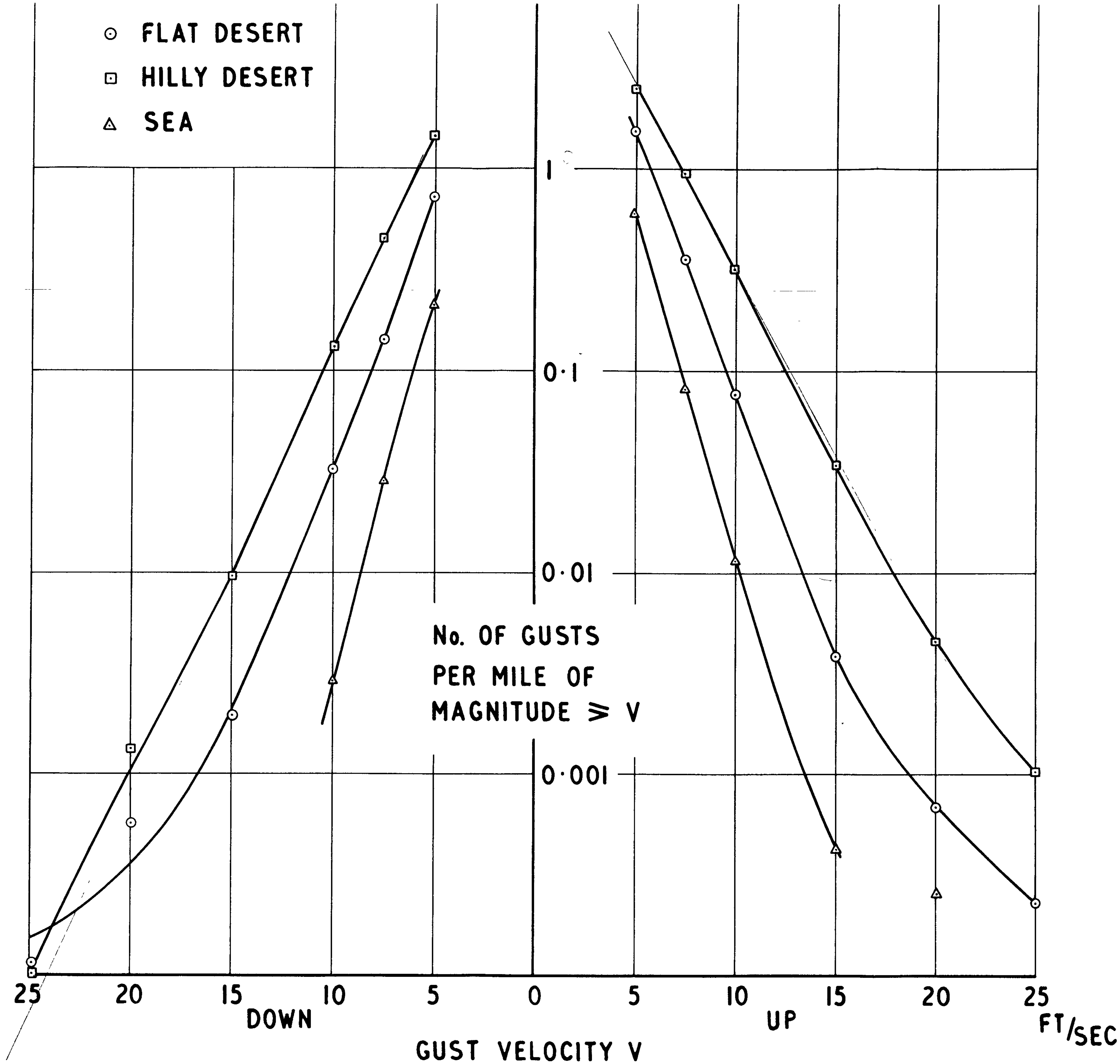

FIG. 7 GUST SPECTRA FOR AFTERNOON FLIGHTS - ALL THE YEAR

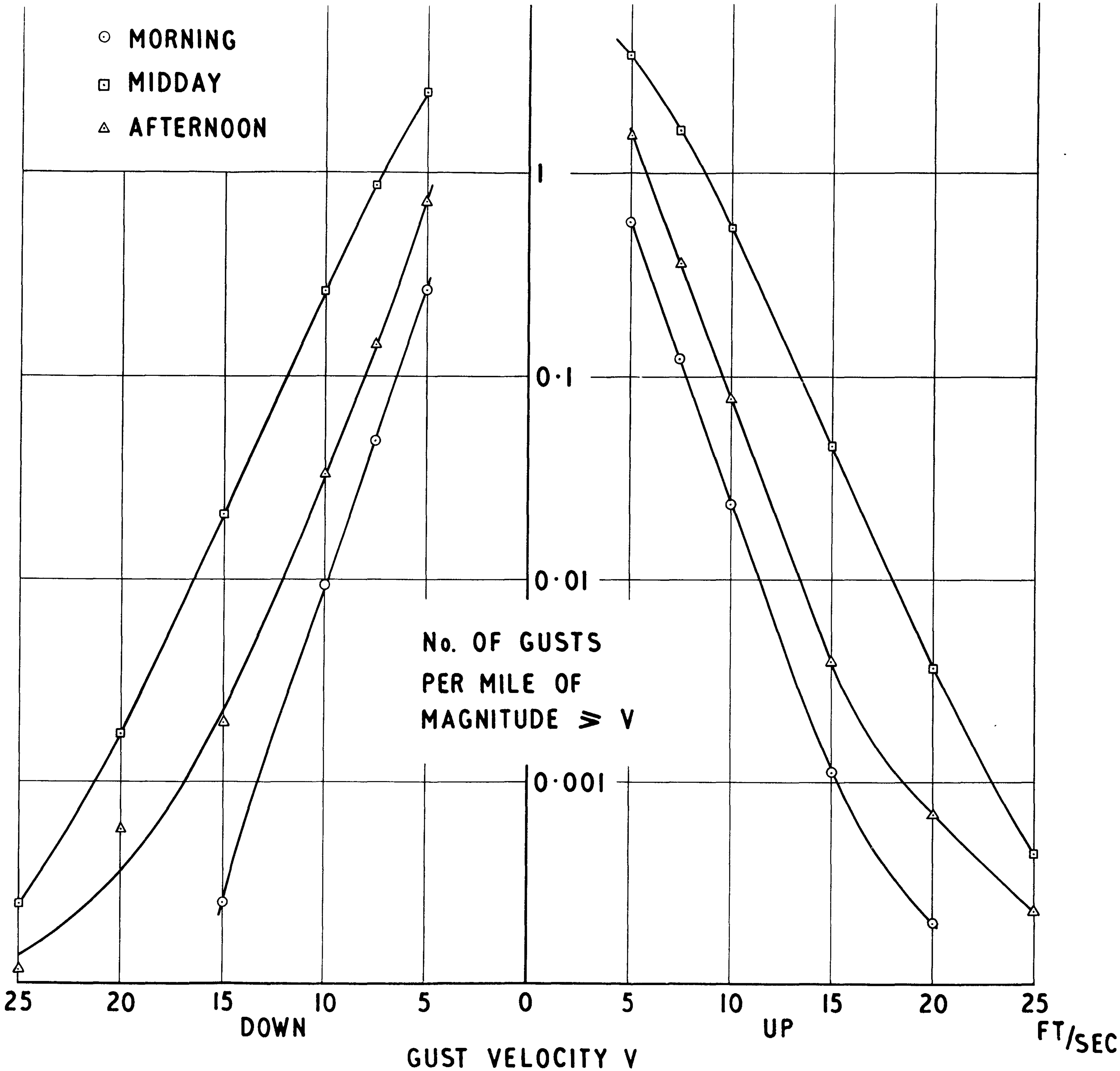

FIG 8 GUST SPECTRA FOR EL ADEM - FLAT DESERT - ALL THE YEAR

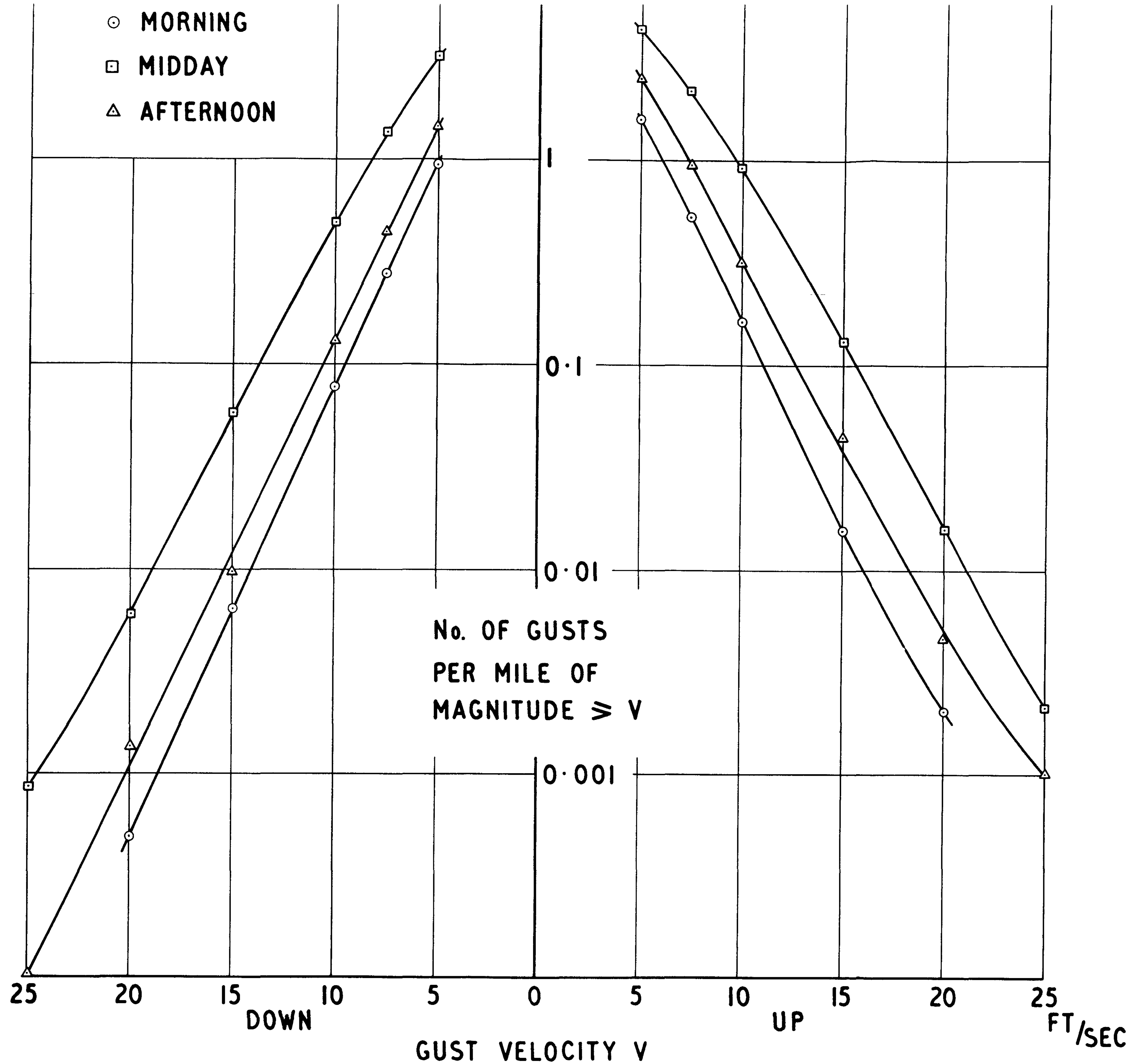

FIG. 9. GUST SPECTRA FOR EL ADEM - HILLY DESERT - ALL THE YEAR.

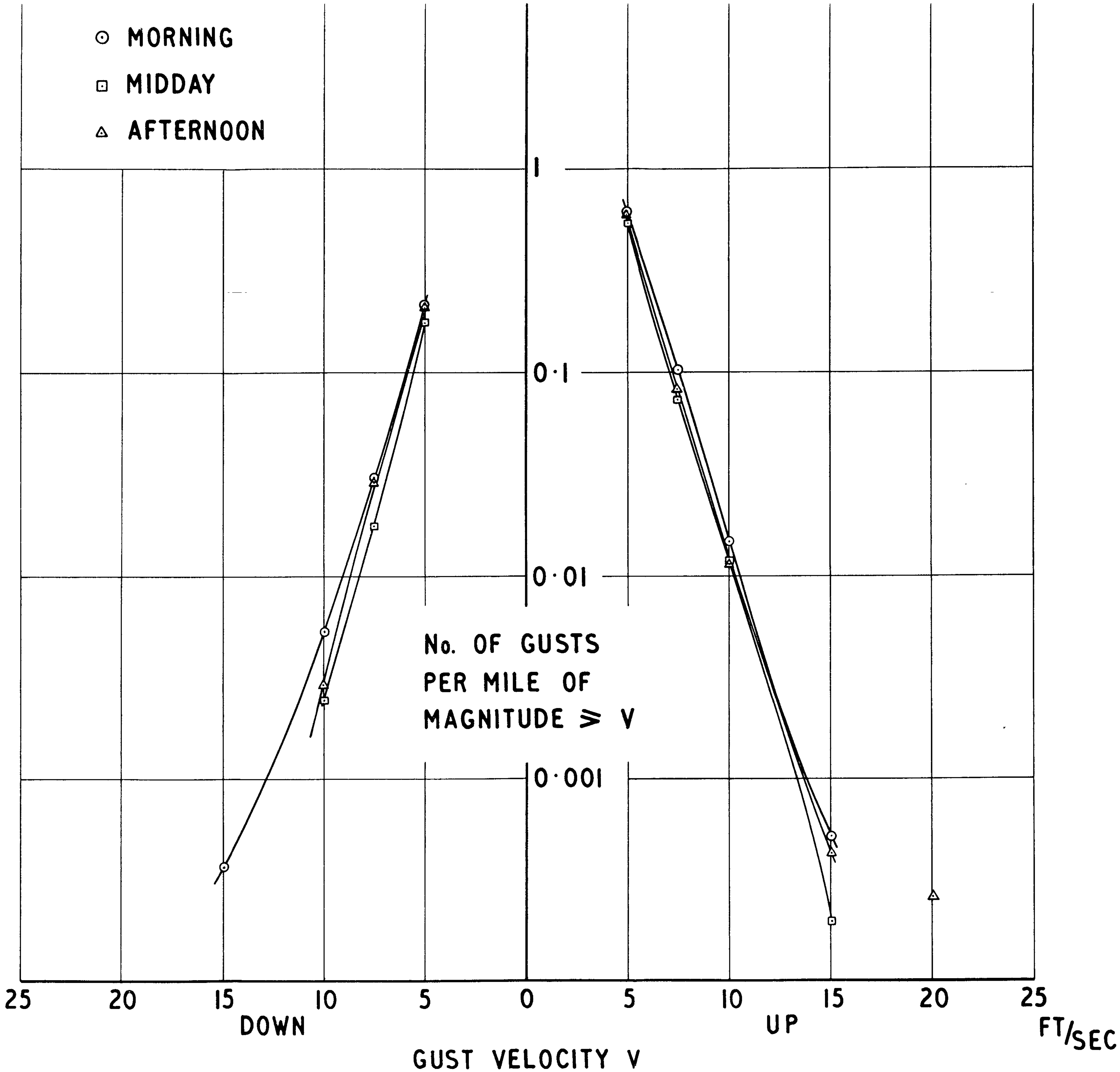

FIG. 10. GUST SPECTRA FOR THE SEA - ALL THE YEAR

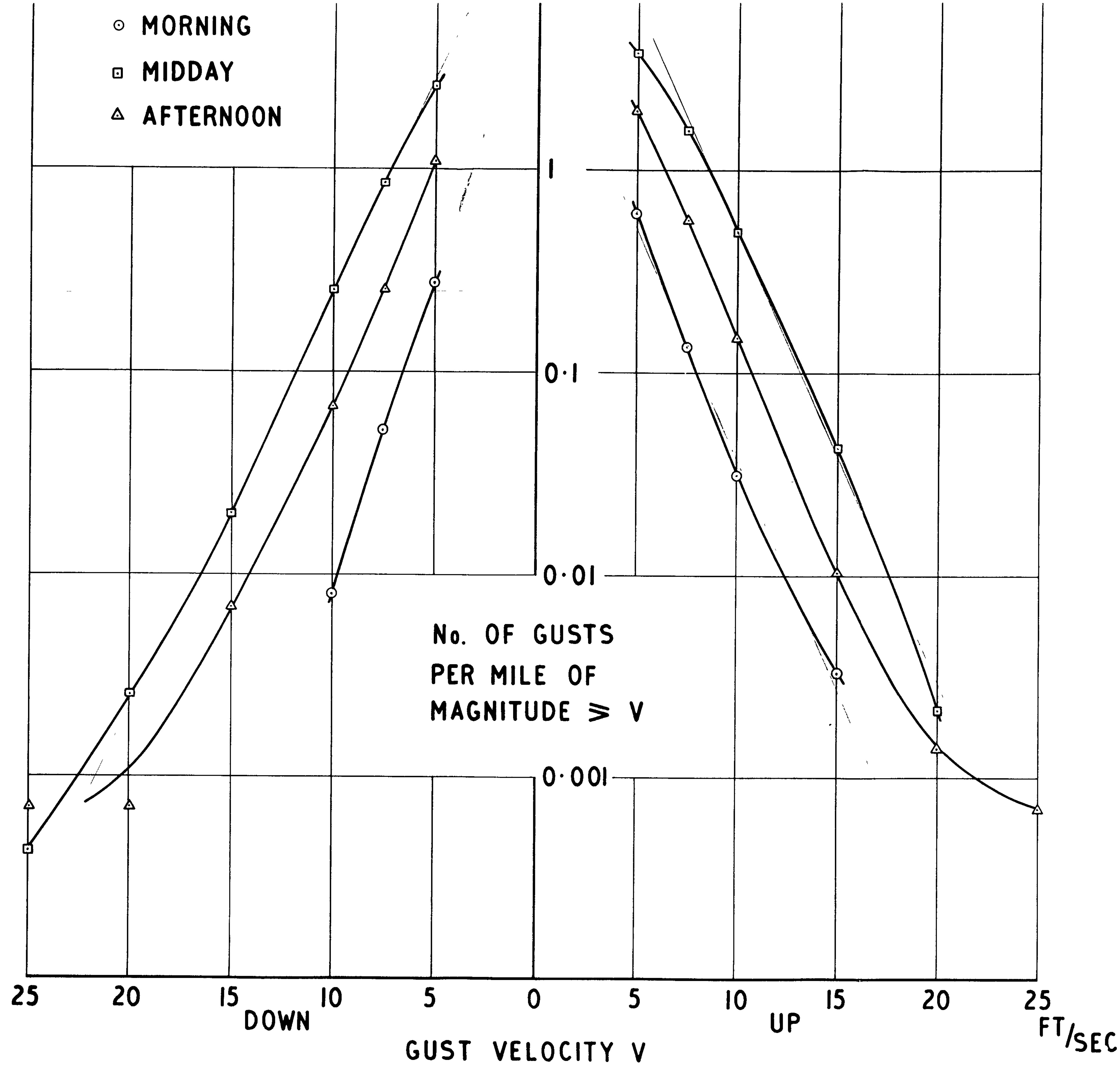

FIG. II. GUST SPECTRA FOR IDRIS - CULTIVATED - ALL THE YEAR

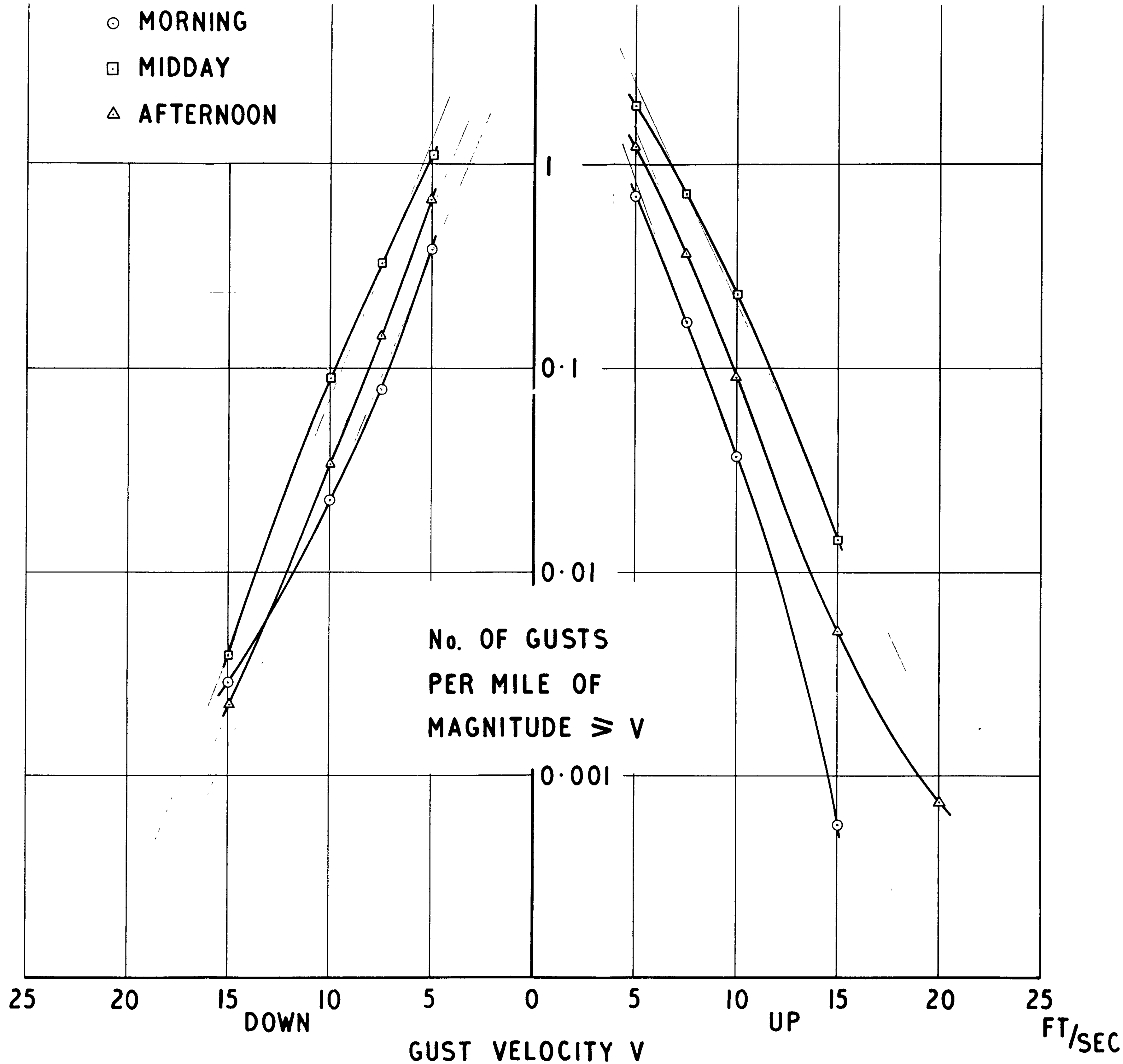

FIG. 12. GUST SPECTRA FOR IDRIS - COASTAL - ALL THE YEAR.

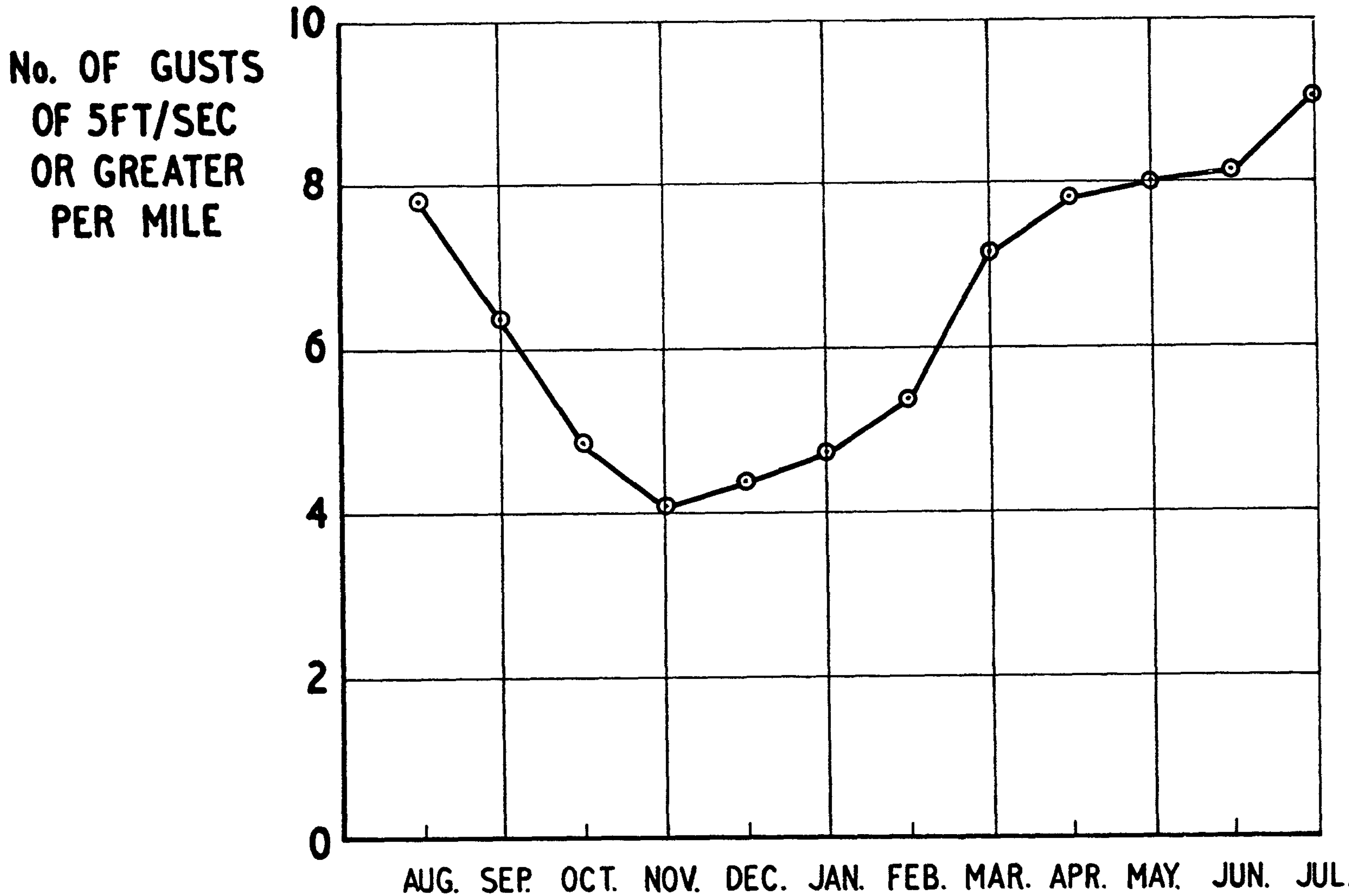

FIG. 13. ANNUAL VARIATION IN GUST FREQUENCY ON MIDDAY FLIGHTS OVER FLAT DESERT.

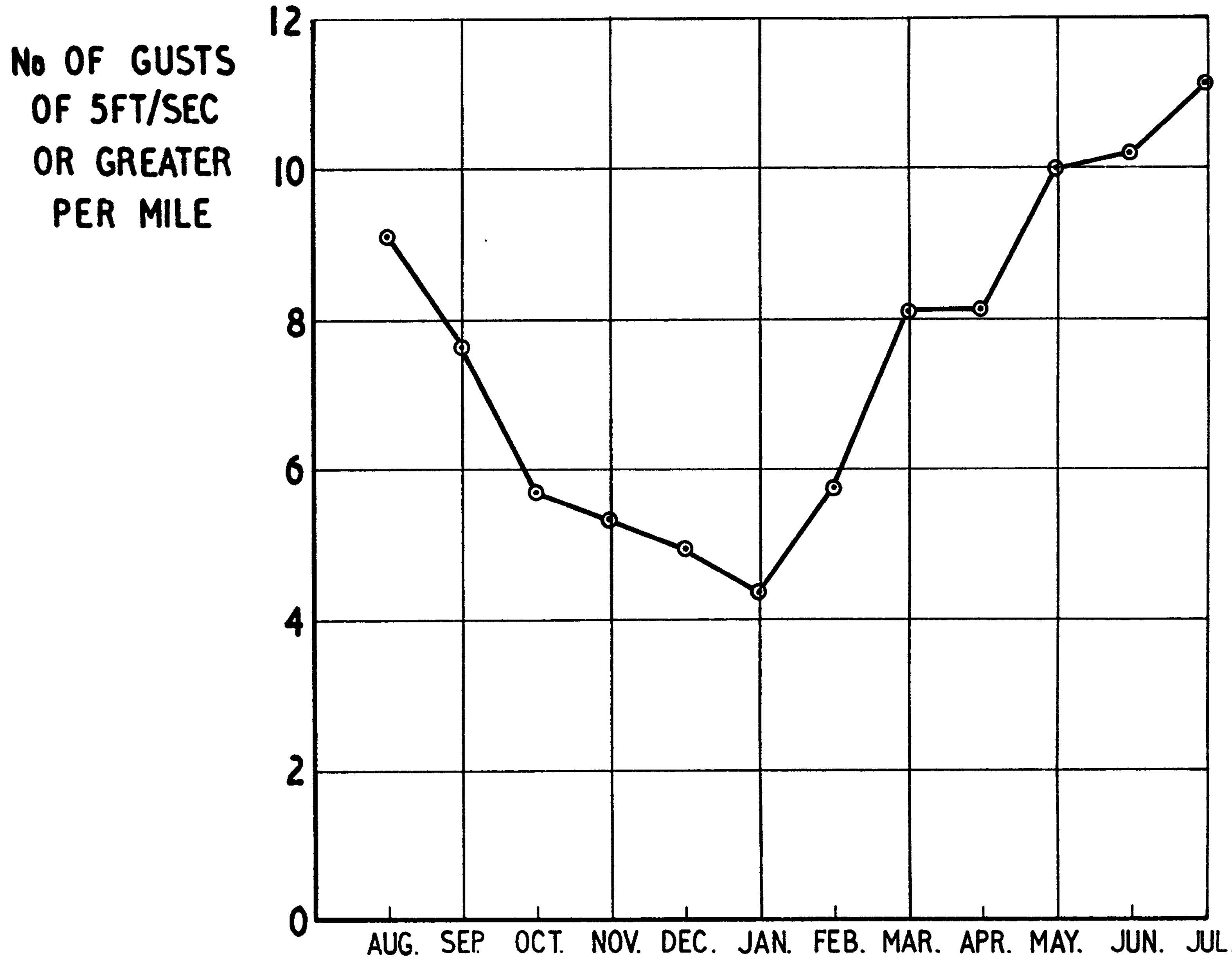

FIG.14. ANNUAL VARIATION OF GUST FREQUENCY ON MIDDAY FLIGHTS OVER HILLY DESERT.

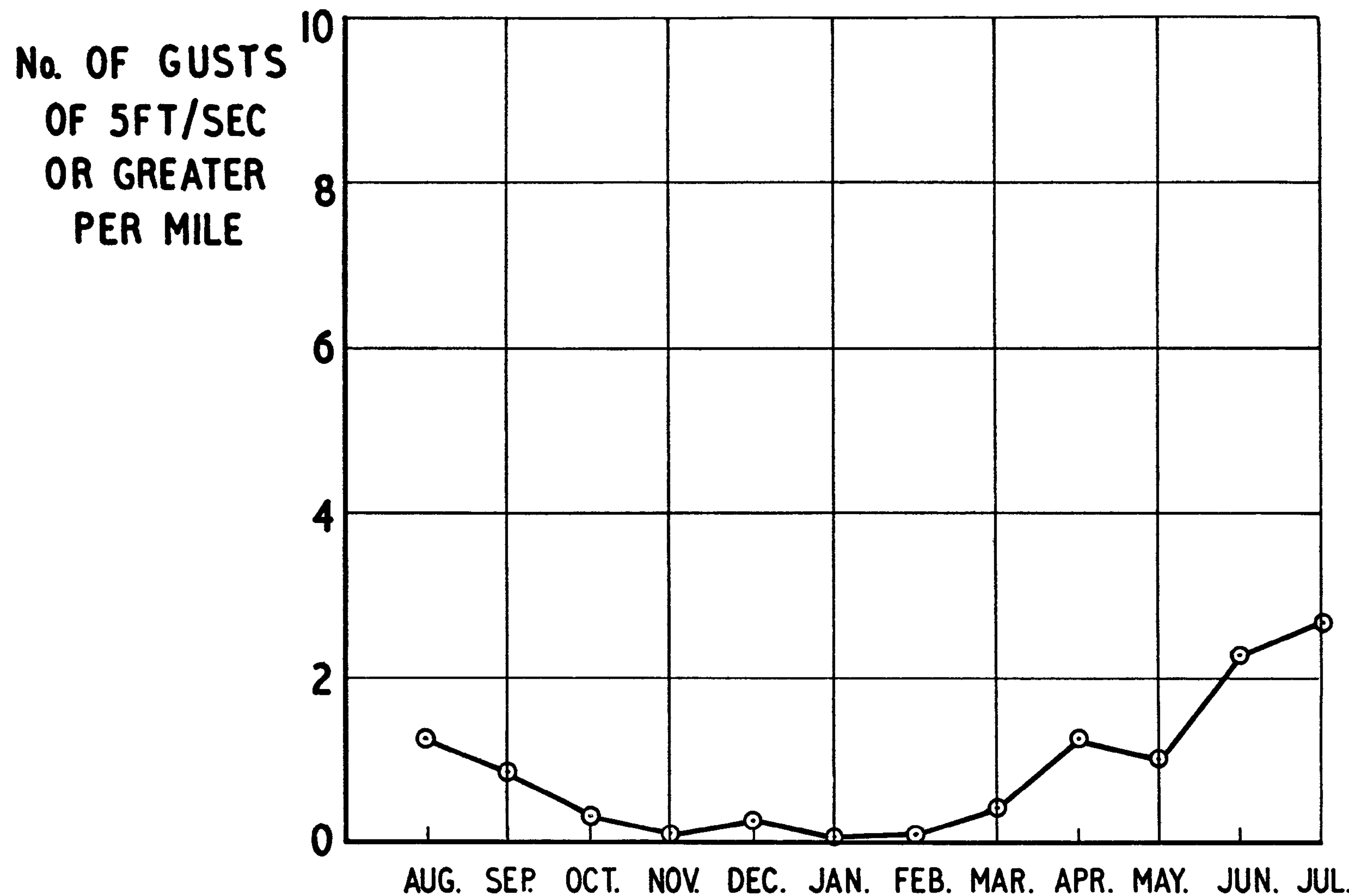

FIG. 15. ANNUAL VARIATION IN GUST FREQUENCY ON MORNING FLIGHTS OVER FLAT DESERT.

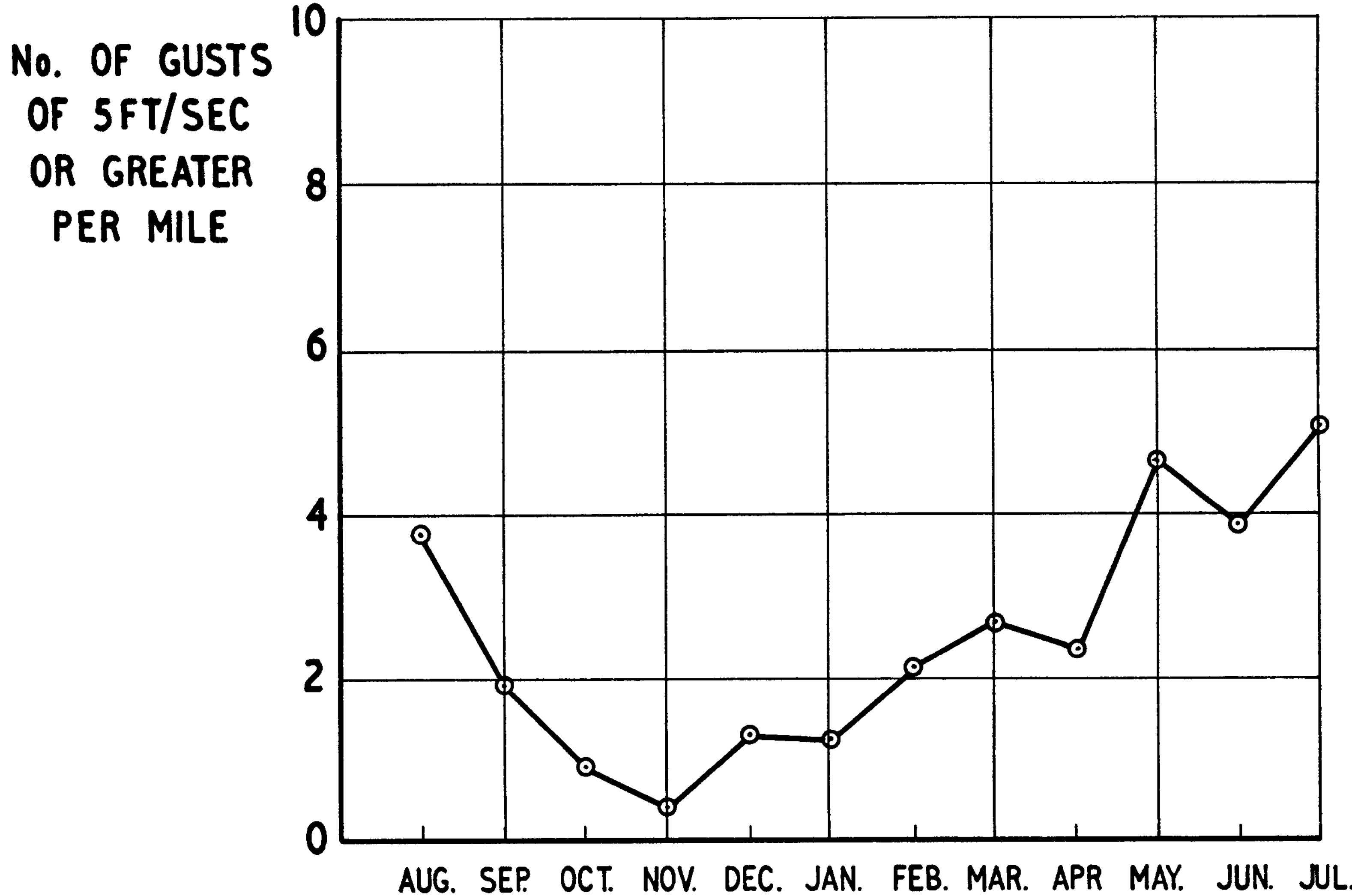

FIG.16. ANNUAL VARIATION IN GUST FREQUENCY ON MORNING FLIGHTS OVER HILLY DESERT.

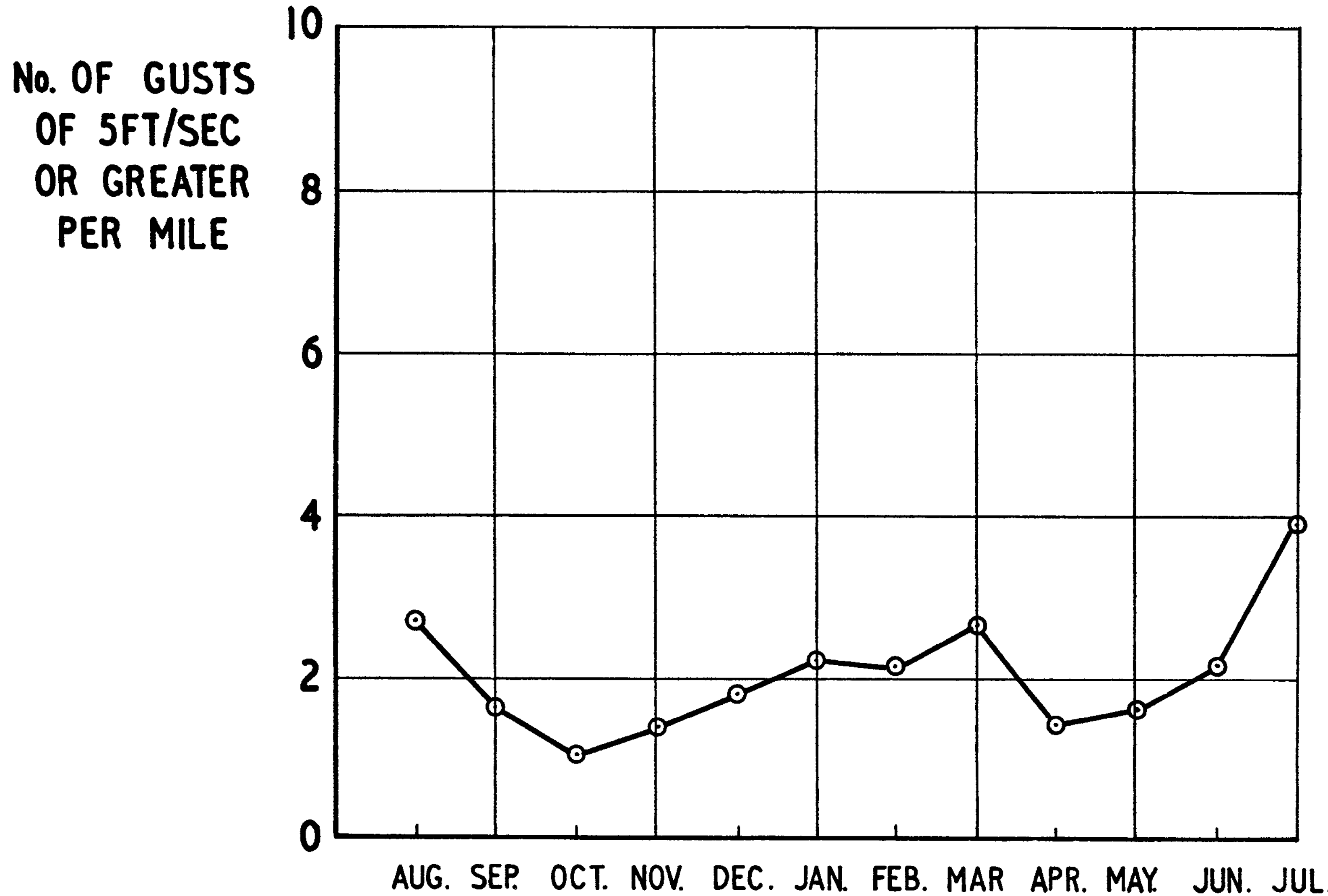

FIG.17 ANNUAL VARIATION IN GUST FREQUENCY ON AFTERNOON FLIGHTS OVER FLAT DESERT.

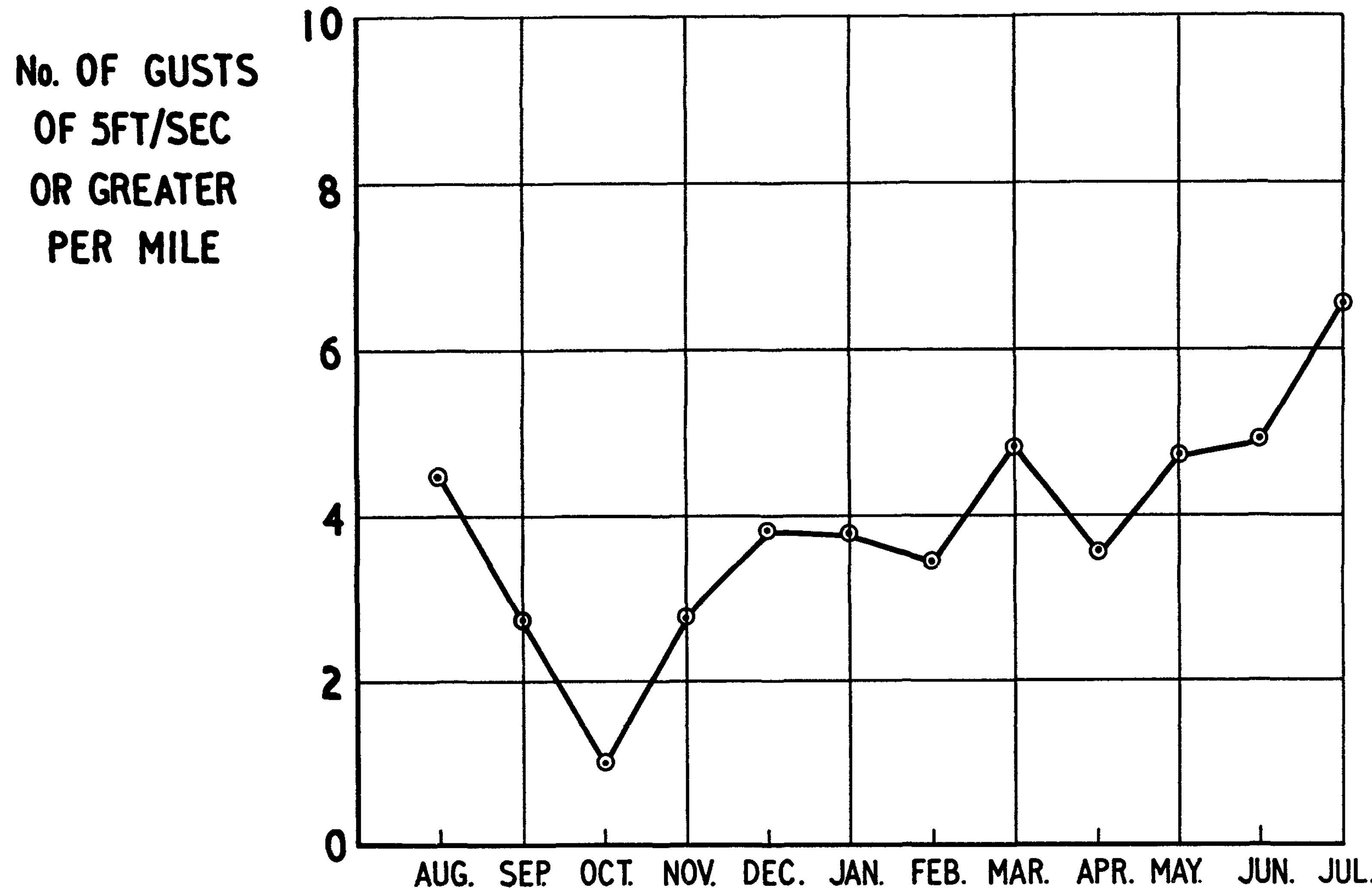

FIG.18. ANNUAL VARIATION IN GUST FREQUENCY ON AFTERNOON FLIGHTS OVER HILLY DESERT.

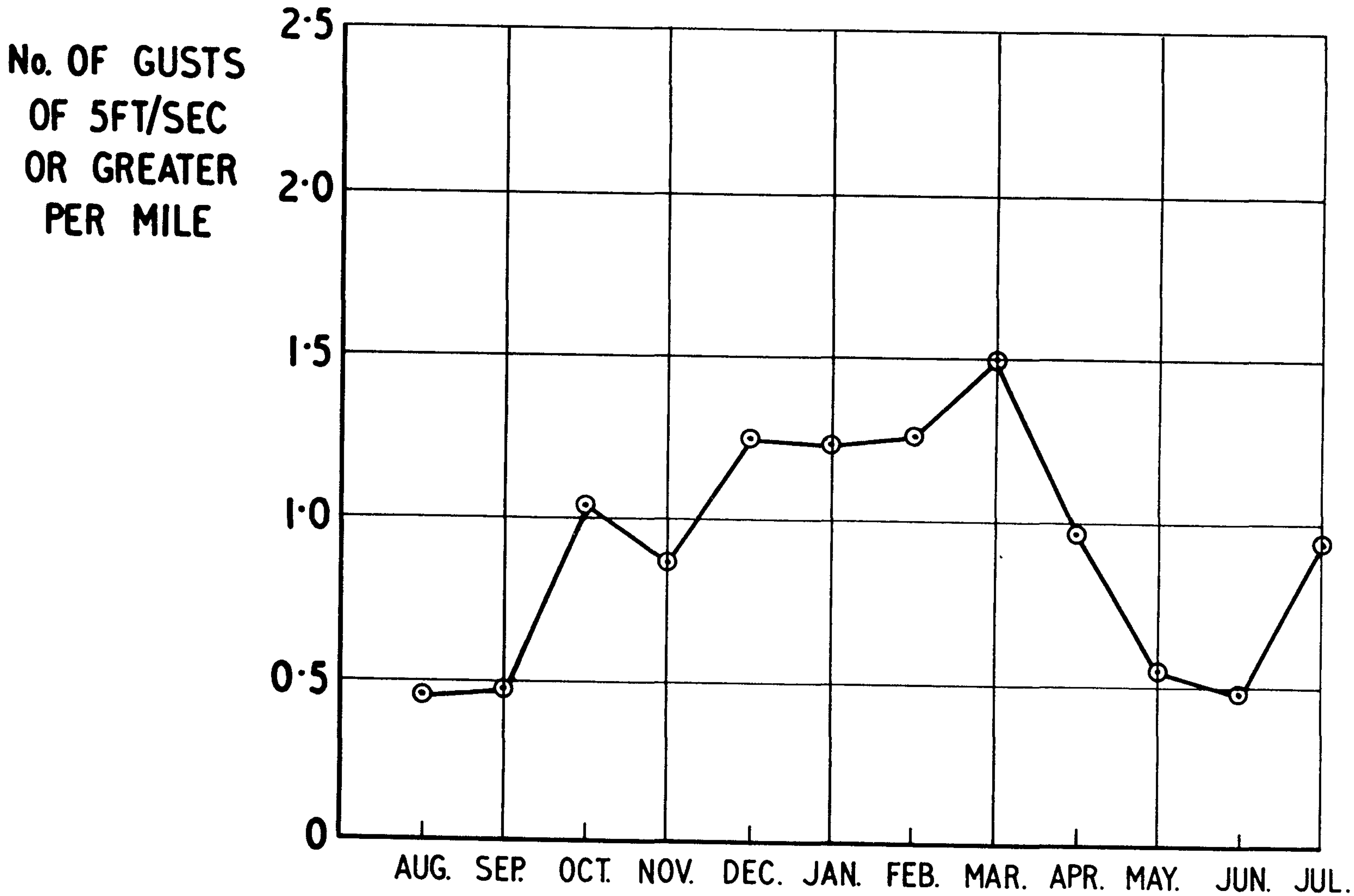

FIG. 19. ANNUAL VARIATION IN GUST FREQUENCY OVER THE SEA (ALL TIMES OF DAY.)

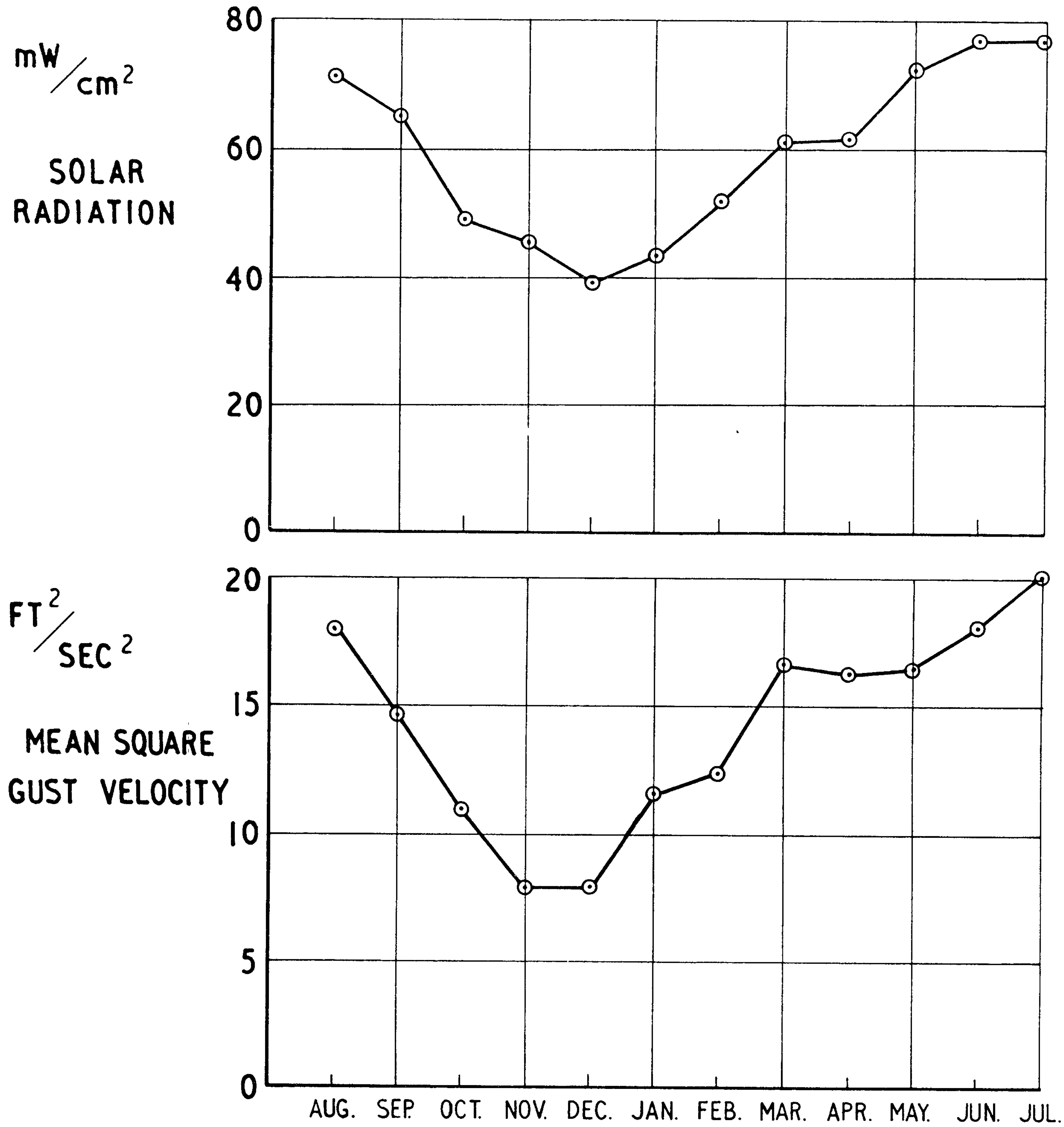

FIG. 20. COMPARISON OF SOLAR RADIATION AND MEAN SQUARE GUST VELOCITY OVER FLAT DESERT AT MIDDAY — MONTHLY AVERAGES.

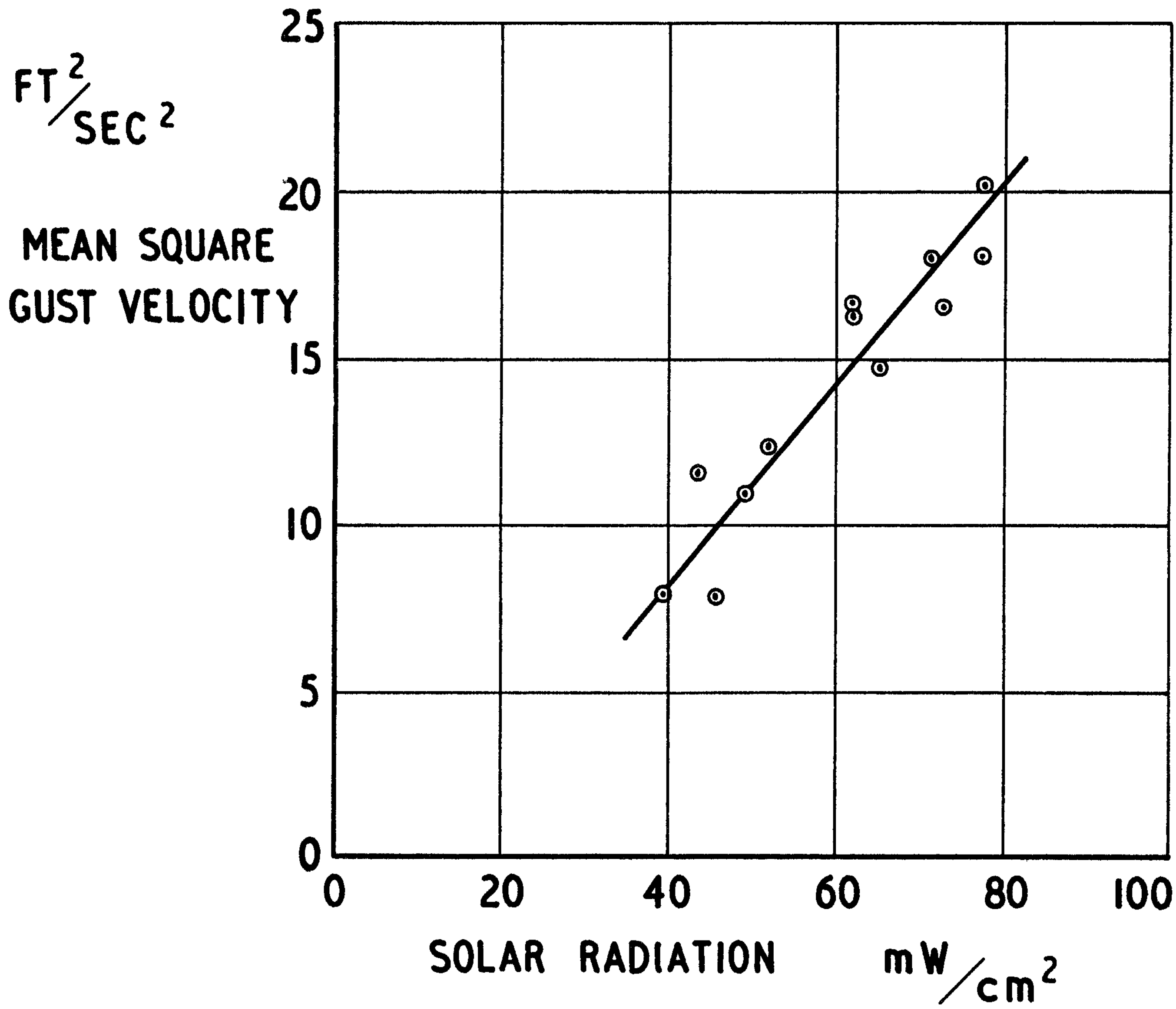

FIG. 21. RELATION BETWEEN SOLAR RADIATION AND MEAN SQUARE GUST VELOCITY OVER FLAT DESERT.

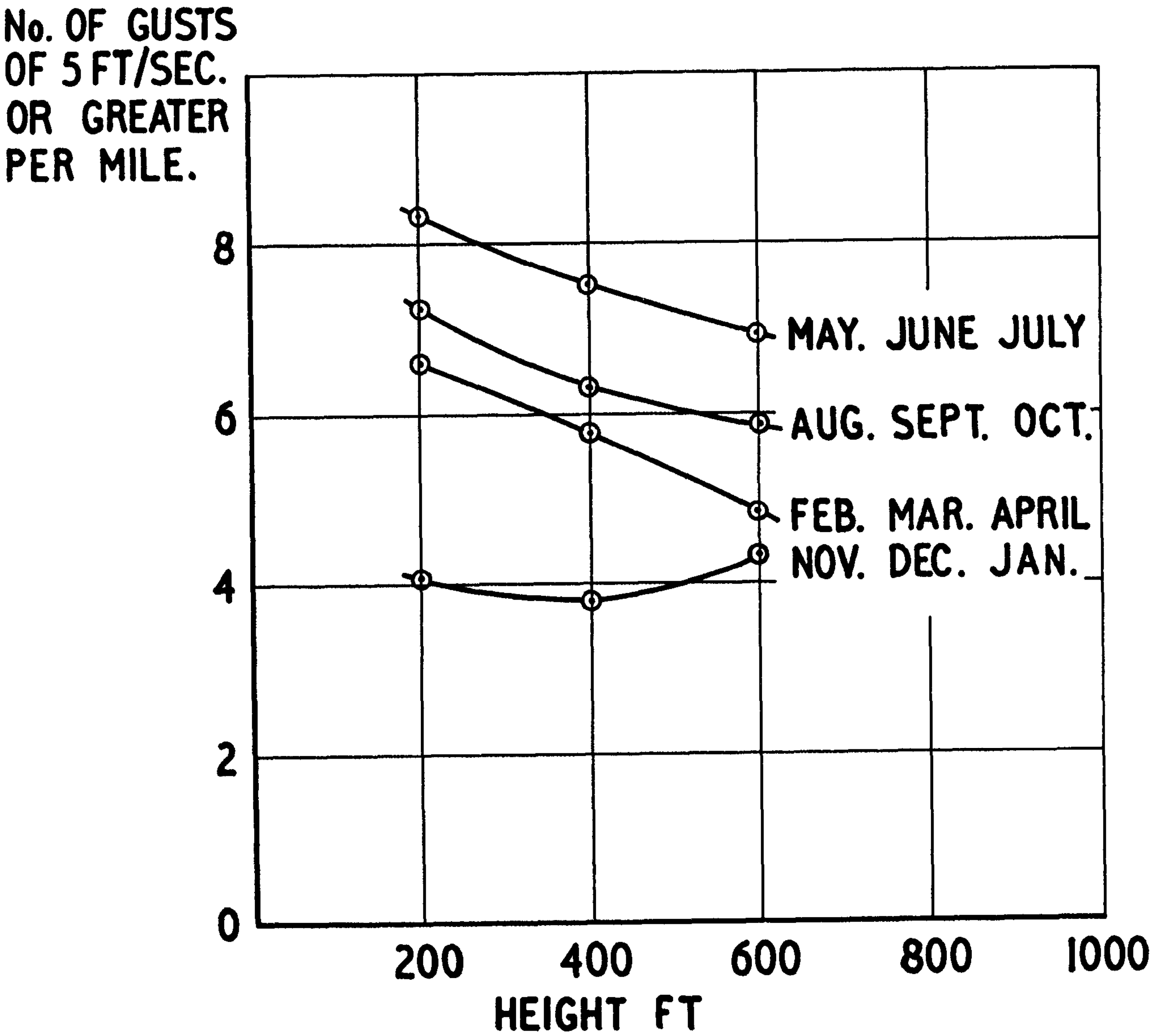

FIG. 22. VARIATION OF GUST FREQUENCY WITH HEIGHT OVER FLAT DESERT.

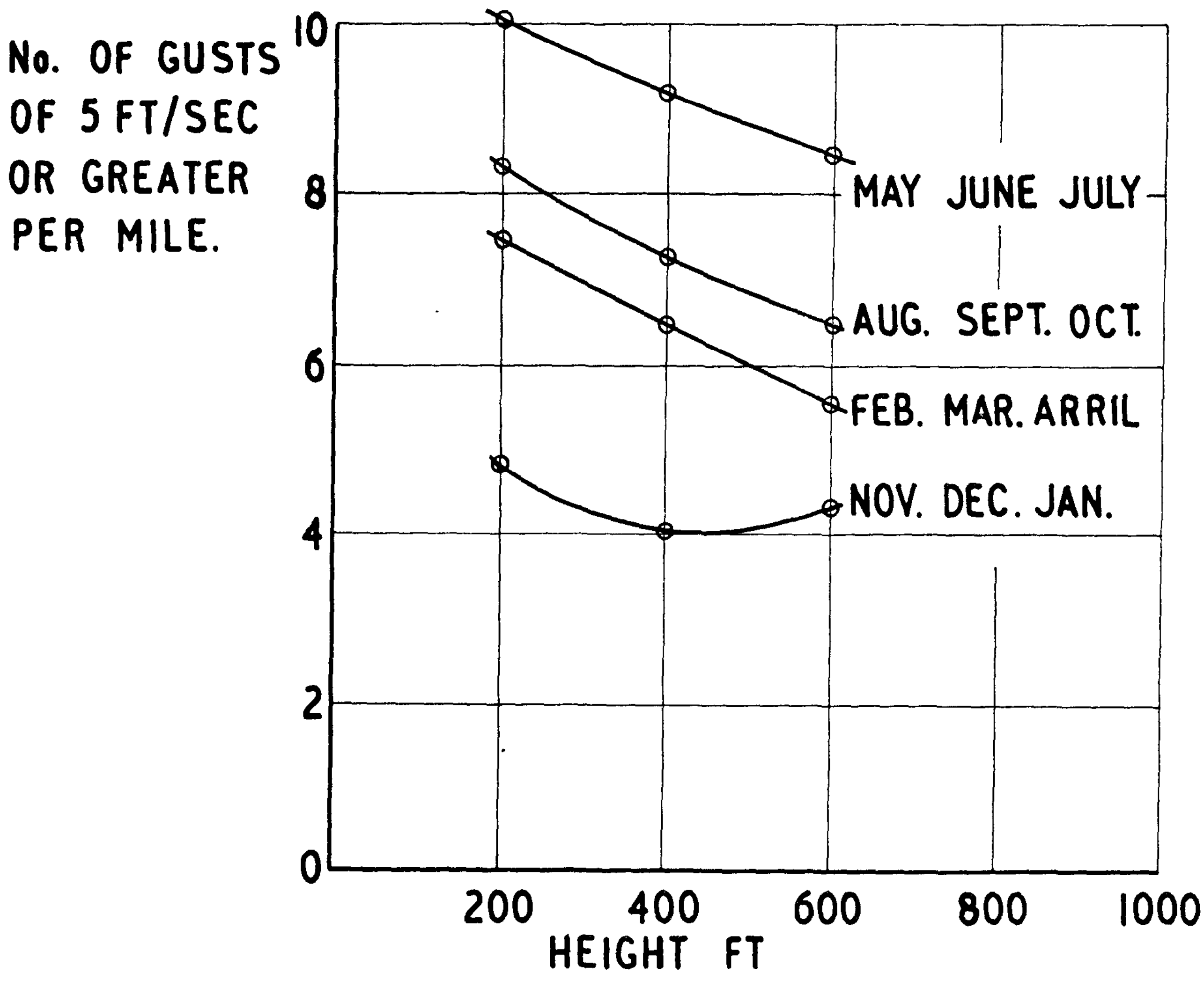

FIG.23. VARIATION OF GUST FREQUENCY WITH HEIGHT OVER HILLY DESERT.

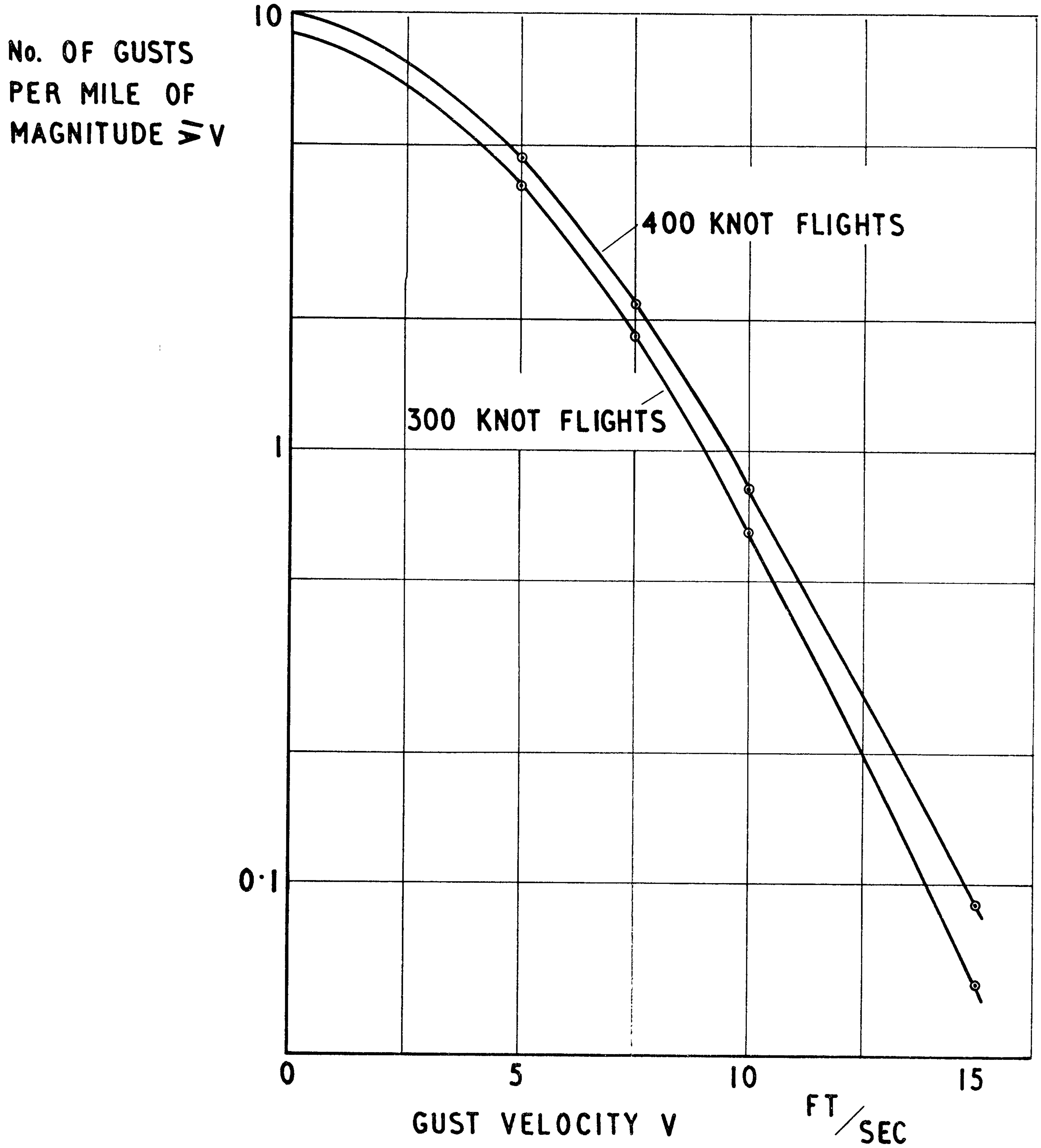

FIG. 24. COMPARISON OF GUST SPECTRA FOR FLIGHTS AT 300 AND 400 KNOTS.

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GUSTS AT LOW ALTITUDE IN NORTH AFRICA. Bullen, N.I. September, 1961.

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The effect of compressibility on the gust alleviation factors for speeds up to a Mach number of 0.6 is shown to be small.

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