C.P. No. 522
(21,875)
A.R.C. Technical Report

C.P. No. 522
(21,875)
A.R.C. Technical Report

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

A Measured Power Spectrum of the Vertical Component of Atmospheric Turbulence

by

J. K. Zbrozek and D. M. Ridland

LONDON: HER MAJESTY'S STATIONERY OFFICE

1960

FOUR SHILLINGS NET

C.P. No.522

U.D.C. No. 629.13:551.55

Technical Note No. Aero 2681

March, 1960

ROYAL AIRCRAFT ESTABLISHMENT

A MEASURED POWER SPECTRUM OF THE VERTICAL COMPONENT OF ATMOSPHERIC TURBULENCE

by

J. K. Zbrozek and D. M. Ridland

SUMMARY

An experimental study of aircraft response to turbulent air is being made using power spectrum methods. Consideration is given here to the spectral technique as applied to measurements of atmospheric turbulence and a number of theoretical relationships are quoted. The spectrum of the gust vertical velocity component obtained from the first sample of turbulence analysed is discussed. There appears to be a significant difference at long wavelengths between the present measurements and those available from the U.S.A. If this difference is substantiated by further measurements it will have a considerable effect on gust load predictions on large aircraft. This stresses the urgent need for more experimental data on atmospheric turbulence especially at long wavelengths.

LIST OF CONTENTS

LIST OF APPENDICES

LIST OF ILLUSTRATIONS

1 INTRODUCTION

In studies of aircraft behaviour in turbulent air, knowledge is required of the turbulence energy distribution throughout a wide frequency range. The energy distribution is given by the power spectral density function, which is usually expressed as a function of space frequency $\Omega = \frac{2\pi}{\lambda}$, rad ft^{-1}, or of inverse of wavelength ($^1/\lambda$). The range of wavelengths which affects the response of a rigid aircraft is of the order of 300 ft < λ < 10,000 ft. When the elasticity of the airframe is taken into account much shorter wavelengths are also important, starting say from λ = 20 ft[1]. Thus, the power spectrum of atmospheric turbulence is required over a wavelength range of say 10 < λ < 50,000 ft. It should be added that in some applications, for example in estimating the frequency of crossing a given level of aircraft response, a knowledge of the spectrum behaviour at much higher frequencies (shorter wavelengths) is required.

The R.A.E. is engaged at present in the experimental study of aircraft response to turbulent air. The value of such a study is much increased if the input is measured directly and one of the phases of this study was accordingly devoted to the measurement of the vertical component of atmospheric turbulence. This note presents the results analysed so far and discusses briefly the further work planned.

2 THE TECHNIQUE OF MEASUREMENT

Aircraft incidence was measured by a wind vane mounted on the nose boom of the aircraft. The vane readings were corrected for the heaving and pitching motion of the aircraft, but no correction was made for aircraft elasticity. Nose boom flexibility was neglected, as nose boom frequency (14 c.p.s.) was well outside the range of frequencies of interest during present investigation. The technique is basically one developed by Cornell Aero Lab[2] and used since by N.A.C.A.[3,4].

Great care was taken in the design of the instrumentation system to ensure that the instruments had satisfactory resolution and dynamic response.

It is believed, that the accelerometer and the rate gyro, the basic elements of the instrumentation, which were specially developed for this work, are superior to any similar instruments used up till now in flight work[15]. As there is no reliable way of correcting the vane readings for unsteady up-wash, an attempt was made to minimise the steady upwash at the vane (position error), in the hope of thereby also reducing the unsteady effects. Largely because of uncertainties with the wind vane, only a very limited number of complete records in adequately severe turbulent conditions have so far been obtained. The results of the analysis of a representative sample form the basis of this note. Efforts are now being given to improving the wind vane equipment.

During the test the true air speed was 534 f.p.s. and pressure altitude about 2,500 ft. The flight test conditions and meteorological situation are given in Appendices 1 and 2.

3 ANALYSIS OF THE MEASURED DATA

The sample of turbulence analysed was 100 sec long i.e. in terms of distance flown 53,400 ft. The record was read at intervals of 0.05 sec (26.7 ft) and from the resulting 2000 points an auto-correlation function was computed, Fig.1. The maximum lag of τ = 6.35 sec was determined by the capacity of the computing machine (127 lags). In an attempt to obtain information about the correlation function at lags larger than 6.35 sec, the auto-correlation function was computed using every fourth reading, the reading interval was then 0.2 sec, Fig.2. The validity of the correlation function at large lags is doubtful due to the comparatively short sample length (100 sec).

The cosine transform of the correlation function, which is the power spectral density function was then computed and the results are plotted in Fig.3. The circles denote the transform of the correlation function with 6.35 sec maximum lag and the crosses the transform of the correlation function with 25.4 sec maximum lag. Taking into account the length of the sample analysed and the reading interval it is believed that the spectrum estimates should represent the encountered turbulence fairly reliably for frequencies between 0.1 c.p.s. and 5 c.p.s. (wavelengths of 5,000 ft to 100 ft).

In Fig.4 the power spectrum (of vertical velocity) obtained directly from the vane reading without any correction for aircraft motion (triangles) is compared with the spectrum of the vertical component of turbulence i.e. vane reading corrected for aircraft motion (circles). It can be seen that the correction is small at all frequencies and vanishes for higher frequencies. The ratio of the uncorrected spectrum to the spectrum corrected for aircraft motion is the square of the incidence frequency response of the aircraft[5]. The values of this function suggested by Fig.4 are qualitatively in agreement with theory, as can be seen in Fig.11 of Ref.5. It should be mentioned, that the aircraft used in the present tests was flown with very low static stability, and the short period frequency was of the order of 0.5 c.p.s. at the test condition.

The two peaks on the spectrum of Fig.3 are due to airframe elasticity, for which the readings were not corrected. The frequencies of the first two structural modes, relevant to the flight conditions of the experiment, are indicated in Fig.3. It can be seen that the resolution of the measured spectrum is extremely good and shows faithfully the aeroelastic effects.

4 SOME THEORETICAL RELATIONSHIPS RELEVANT TO MEASUREMENTS OF ATMOSPHERIC TURBULENCE

There are indications that within some finite volume atmospheric turbulence can be regarded as homogeneous and isotropic*. It is assumed for the present discussion that the analysed sample of atmospheric turbulence is homogeneous and isotropic.

Let us consider two auto-correlation functions, f(r) and g(r). The first function, f(r), is obtained when the turbulence velocity component u is along the correlation axis, r. This longitudinal correlation function is defined as:

$$f(r) = \frac{\overline{u(x) \times u(x+r)}}{\overline{u^2(x)}} ; \qquad (1)$$

where r is lag in feet. The other "lateral" correlation function g(r) is the auto-correlation function of the velocity component (v or w) perpendicular to the correlation axis r and is defined as:

* By homogeneous turbulence we mean a turbulence having average (statistical) properties which are independent of the origin of measurement; by isotropic, that these properties are independent of a rotation of the reference axes.

$$g(r) = \frac{\overline{w(x) \times w(x+r)}}{\overline{w^2(x)}} ; \qquad (2)$$

with a similar expression for the v component.

In the present case where the vertical component, w, of the atmospheric turbulence was measured, we are dealing with the second correlation function, g(r).

It has been shown that for isotropic turbulence the longitudinal and lateral correlation functions are related by[6,7,8]:

$$g(r) = f(r) + \frac{1}{2} r \frac{\partial f(r)}{\partial r} . \qquad (3)$$

The corresponding power spectra of the longitudinal and transverse components of turbulence can be written:

$$F(\Omega) = \overline{u^2} \frac{2}{\pi} \int_0^\infty f(r) \cos(\Omega r) \, dr \qquad (4)$$

$$G(\Omega) = \overline{w^2} \frac{2}{\pi} \int_0^\infty g(r) \cos(\Omega r) \, dr \qquad (5)$$

and they are similarly related, viz.

$$G(\Omega) = \frac{1}{2} F(\Omega) - \frac{1}{2} \Omega \frac{dF}{\partial \Omega} . \qquad (6)$$

It might be noted that the correlation function can also be obtained from the spectral function by an inverse transform, for example

$$\overline{u^2} f(r) = \int_0^\infty F(\Omega) \cos(\Omega r) \, d\Omega . \qquad (7)$$

The quantity Ω is a "space" frequency in radians per foot and is defined in terms of other known quantities by:

$$\Omega = \frac{2\pi f}{V} = \frac{2\pi}{\lambda} \qquad (8)$$

where f = frequency in c.p.s.

V = speed of flight in f.p.s.

λ = wavelength of turbulence in ft.

The scale of turbulence, L ft, is usually defined as:

$$L = \int_o^\infty f(r)\, dr \qquad (9)$$

or from equation (3) as,

$$L = 2 \int_o^\infty g(r)\, dr\, . \qquad (10)$$

From the above definitions of the turbulence scale it follows that the values of the spectral functions at zero frequency are:

$$F(o) = \overline{u^2}\, \frac{2}{\pi}\, L \qquad (11)$$

$$G(o) = \overline{w^2}\, \frac{1}{\pi}\, L\, . \qquad (12)$$

In flight work, when we measure the turbulence by traversing it with flight velocity, V f.p.s., the conversion from time to length scale is by Taylor's transformation:

$$Vt = r \qquad (13)$$

thus for example the turbulence scale can be obtained from the time correlation by:

$$L = V \int_0^\infty f(\tau)\, \partial\tau \qquad (14)$$

where τ is the correlation lag in seconds.

5 SPECTRA OF ATMOSPHERIC TURBULENCE IN CONTEMPORARY USE

In studies of aircraft response to atmospheric turbulence a knowledge of spectrum shape over the wavelengths of interest is essential. It might be argued that this shape does not have to represent faithfully the characteristics of atmospheric turbulence and that it might be sufficient to have a reasonable approximation. What is however essential is that the same spectral shape is adopted by all users. There is no point in specifying a value of R.M.S. of atmospheric turbulence without stating explicitly to what spectral shape and to what wavelength band it refers.

Some attempt at "standardisation" of the atmospheric turbulence spectrum has been made in U.S.A. Experiments have shown[9,10] that in isotropic turbulence the correlation functions f(r) and g(r) have nearly the form:

$$f(r) = e^{-r/L} \qquad (15)$$

$$g(r) = \left(1 - \frac{1}{2}\frac{r}{L}\right) e^{-r/L} . \qquad (16)$$

The above expressions satisfy both equation (3) and the definitions of turbulence scale equations (9) and (10).

The corresponding expressions for spectra are:

$$F(\Omega) = \overline{u^2}\, \frac{2}{\pi}\, L \frac{1}{1 + \Omega^2 L^2} \qquad (17)$$

$$G(\Omega) = \overline{w^2}\, \frac{L}{\pi}\, \frac{1 + 3\,\Omega^2 L^2}{(1 + \Omega^2 L^2)^2} . \qquad (18)$$

The above, are spectra of one-dimensional turbulence i.e. the turbulence components u, v and w are functions of wavelength (or frequency Ω) along one, the x, axis only.

In some applications, for example in the computation of the response of an aircraft which is (relatively) large in comparison with the turbulence scale, knowledge is required of the turbulence distribution not only along the x axis (longitudinal) but also along the y axis (lateral). Thus we have to know the two-dimensional spectrum where the distribution of, say the w component is a function of Ω_1 along the x axis and of Ω_2 along the y axis. The suggested expression for such a two-dimensional spectrum $G(\Omega_1,\Omega_2)$ is as follows[11,12]:

$$G(\Omega_1,\Omega_2) = \overline{w^2}\,\frac{3L^2}{\pi}\,\frac{L^2\left(\Omega_1^2+\Omega_2^2\right)}{\left[1+L^2\left(\Omega_1^2+\Omega_2^2\right)\right]^{5/2}} . \tag{19}$$

The value of $\overline{w^2}$ is obtained by integration, thus

$$\overline{w^2} = \int_0^\infty \int_0^\infty G(\Omega_1,\Omega_2)\, d\Omega_1\, d\Omega_2 . \tag{20}$$

The one-dimensional spectrum $G(\Omega_1)$ is obtained by integration throughout the range of Ω_2

$$G(\Omega_1) = \int_0^\infty G(\Omega_1,\Omega_2)\, d\Omega_2 = \overline{w^2}\,\frac{L}{\pi}\,\frac{1+3\,\Omega_1^2\,L^2}{\left(1+\Omega_1{}^2\,L^2\right)^2} . \tag{21}$$

It can be seen that the expression (21) is identical with expression (18). Thus, the expressions for one-dimensional spectra e.g. (17) and (18), appear to have practical advantages. They are reasonably simple to handle, satisfy the requirements of isotropy and can be extended to two and three dimensional turbulence.

From quite extensive measurements in the U.S.A. it was concluded that the spectrum of the vertical component of atmospheric turbulence $G(\Omega)$ is well approximated by expression (18) and further that the scale of atmospheric turbulence is of the order $L = 1{,}000$ ft (viz.Ref.13).

It should be remembered however that the expressions for the correlation functions (equations (15) and (16)) were based on experimental evidence obtained from measurements of turbulence in wind tunnels. There is a fundamental difference between the artificially created turbulence in the tunnel and the natural turbulence of the atmosphere. In the tunnel the turbulence is generated by a wire grid and the energy input is steady. Measurements are made some distance behind the grid where the turbulence is decaying without further energy input. The mechanism of energy input to atmospheric turbulence is not well understood at least by the present writers, and although one would expect a similarity between atmospheric and tunnel turbulence spectra at shorter wavelengths where the energy is being transported and dissipated, at longer wavelengths, where the energy input is important, the assumption of similarity ceases to be valid. This is pointed out in Ref.14, where it is shown that for long enough wavelengths the atmospheric turbulence cannot be regarded as isotropic.

From the aircraft engineers, point of view, we are interested whether the expressions (17) and (18) give sufficiently accurate descriptions of atmospheric turbulence within the wavelength range of interest.

The experimental evidence obtained so far seems to indicate that this is so. However, the measured spectra cover only a very small range of meteorological conditions, and wavelengths up to only some 3000 ft (with the exception of Crane and Chilton[4] where results for wavelengths up to 60,000 ft are given). In aircraft studies especially on future aircraft the most important part of the spectrum probably lies somewhere between wavelengths of 1000 ft and 10,000 ft, but in this range experimental information is scarce.

6 ANALYSIS OF THE MEASURED SPECTRUM

6.1 Turbulence scale

An attempt was made to establish the scale of turbulence, using the definition of equation (10). Fig.5 shows the integral $\int_0^\tau g(\tau)\, d\tau$ of the measured correlation function. It appears that in spite of oscillations and experimental scatter, this integral converges to a value of approximately 0.9 sec, which gives a turbulence scale, $L \simeq 960$ ft. This is very close to the generally assumed value of $L = 1000$ ft for atmospheric turbulence. It should be noted that the measured correlation function $g(\tau)$, Fig.1, cannot be approximated satisfactorily either by expression (15) or by (16); the relationship between the measured spectrum results and the analytical form is considered further in section 6.4.

6.2 Inertial subrange

From inspection of Fig.3 it appears that the inertial subrange is from a frequency of about 1 c.p.s. upwards i.e. from a wavelength of approximately 550 ft towards shorter wavelengths. In this range the measured power decrease conforms very closely to the $\Omega^{-5/3}$ law; a line with slope $-5/3$ is drawn through the experimental points of Fig.3 to illustrate this point.

6.3 Spectrum near zero frequency

The estimated variance of the measured gust velocity, $\overline{w^2} = 6.48\ \text{ft}^2\ \text{sec}^{-2}$, can be used in equation (12) along with the turbulence scale length, $L = 960$ ft, deduced in section 5.1, to estimate the power in the spectrum at zero frequency. The value obtained, $G(f=0) = 23.6\ \text{ft}^2\ \text{sec}^{-1}$ (or $G(\Omega=0) = 1980\ \text{ft}^3\ \text{sec}^{-2}$) is shown in Fig.3.

6.4 Comparison with analytical expression (equation (18))

In Fig.6 the expression (18) for $G(\Omega)$ has been fitted to the experimental points; one might conclude that the agreement is reasonably good. However in order to fit the analytical expression for $G(\Omega)$ a turbulence scale of L = 250 ft had to be assumed. This value of turbulence scale does not agree with estimates based on equation (10), para.5.1, and with generally accepted values. At higher frequencies the analytical expression decreases more rapidly (Ω^{-2}) than the experimental values. The experimental spectrum suggests that in this particular case more of the energy of the turbulence is found at higher frequencies than can be concluded from the analytical expression and the value of turbulence scale now generally in use.

6.5 Comparison with other measurements

Fig.7 shows a comparison between a few previously measured turbulence spectra and the present results. It should be mentioned that by far the most comprehensive measurements are those of Crane and Chilton[4]. It is interesting, and perhaps significant, that for the wavelengths between 500 ft and 100 ft there is good numerical agreement between the present measurements and those of Ref.4. At longer wavelengths the present measurements show considerably less power than the Crane and Chilton curve. However, the R.M.S. of turbulence as measured by Crane and Chilton uses about 5 f.p.s. whereas the R.M.S. of the present measurements is approximately 2.54 f.p.s. One is inclined to suggest that the shape of the spectrum, and thus the turbulence scale, is a function of turbulence intensity. In other words at short wavelengths the turbulence spectrum is independent of the turbulence intensity, and increasing turbulence intensity, as defined by the R.M.S., increases the value of the spectrum at long wavelengths only. It should be remembered however that the present spectrum was estimated from a sample length of only 53,400 ft, so the estimates at longer wavelength may not represent closely the true atmospheric conditions. More light will be thrown on this question when further samples are analysed. As was mentioned before, the spectrum density in the range of 1000 ft to 10,000 ft wavelengths plays the dominant part in studies of aircraft loading in turbulence, and it is in this range that we appear to have discrepancies between different measurements of turbulence. Some more and varied experimental data are urgently required.

7 CONCLUDING REMARKS

Measurements of the spectrum of atmospheric turbulence which are considered reliable, have been made. Further development of the technique is now in hand and this will enable the measurements to be extended over a much wider frequency band and with further improvement in accuracy.

The measured spectrum differs somewhat from the spectra measured in U.S.A. If this difference is a real one, it can have a large effect on the basis for estimating the gust loads on aircraft, especially on large aircraft. No significance, as yet, can be attached to this difference, as only one turbulence spectrum has been measured. There is an urgent need for further measurements, particularly at low frequencies (long wavelengths). The technique of measuring spectra is well advanced and successful studies are now possible.

LIST OF REFERENCES

No.	Author	Title, etc.
1	Zbrozek, J.K. Pasquill, F.	Note on conditions for which data on the power spectra of atmospheric turbulence are required. C.P. No.474. January, 1959.
2	Notess, C.B. Eakin, G.J.	Flight test investigation of turbulence spectra at low altitude using a direct method for measuring gust velocities. Rep. No. VC-839-F-1. Cornell Aero. Lab. Inc., also W.A.D.C. Tech. Rep. 54-309 July, 1954. Also PB.133167.
3	Chilton, R.G.	Some measurements of atmospheric turbulence obtained from flow-direction vanes mounted on an airplane. N.A.C.A. TN 3313. 1954.
4	Crane, H.L. Chilton, R.G.	Measurements of atmospheric turbulence over a wide range of wavelength for one meteorological condition. N.A.C.A. TN 3702. ARC 18699. June, 1956.
5	Zbrozek, J.K.	Longitudinal response of aircraft to oscillatory vertical gusts. ARC.18,940. November, 1955.
6	von Kármán, T.	Journal of Aeronautical Sciences. Vol.4, p.131. 1937.
7	von Kármán, T. Howarth, L.	Proc. Royal Society, A, 164, p.192, 1938.
8	Taylor, G.I.	Some recent developments in the study of turbulence. Proceedings of the Fifth International Congress for Applied Mechanics. Cambridge, Mass., p.294, 1938.
9	Dryden, H.L.	Turbulence investigations at the National Bureau of Standards. Proceedings of the Fifth International Congress for Applied Mechanics. Cambridge, Mass., p.362, 1938.
10	Liepmann, H.W. Laufer, J. Liepmann, K.	On the spectrum of isotropic turbulence. N.A.C.A. TN 2473. November 1951.
11	Ribner, H.S.	Spectral theory of buffeting and gust response; unification and extension. Journal of Aero. Sciences Vol.23, No.12, 1956.
12	Etkin, B.	Dynamics of flight. Stability and control. New York - John Wiley and Sons Inc. London - Chapman and Hall Ltd., Chap.10, pp.310-340, 1959.

LIST OF REFERENCES (Contd)

No.	Author	Title, etc.
13	Press, H. Meadows, M.T.	A re-evaluation of gust-load statistics for application in spectral calculations. N.A.C.A. TN 3540, 1955.
14	Priestley, C.H.B. Sheppard, P.A.	Turbulence and transfer processes in the atmosphere. Quarterley Journal of Royal Meteorological Society. Vol.78, No.338, pp.488-527, October 1952.
15	Ridland, D.M.	Measurements of the longitudinal frequency response to elevator movement of a Meteor 7 aircraft. M.O.A. Unpublished Report.

APPENDIX 1

TEST CONDITIONS ON 22ND JANUARY 1959

Aircraft:	Meteor 7 VW.412
Speed:	300 knots I.A.S.
Height:	2,500 ft with altimeter set at 1013 m. bars
Course:	90° out, procedure turn, 275° return approximately. (Compass)
Track:	Erith to Wratting Common. Wratting Common to Erith.
Recordings:	(i) 3½ mins on 90° (100 secs sample from here)
	(ii) ½ min gentle turn onto 275°
	(iii) 3 mins on 275°
Airborne:	1501 hours. 25 mins duration
Fuel:	500 gallons on ground
	420 gallons at start of records } roughly
	330 gallons at end of records } roughly
Observed met:	Small amounts of broken Cu.
	Cloud base 3,800 ft with altimeter set at 1013 m. bars

APPENDIX 2

WEATHER CONDITIONS ON 22ND JANUARY 1959 FOR THE ROUTE WRATTING COMMON TO NEAR BEDFORD - PERIOD 1500-1515 GMT

Meteorological Situation:	Depression centred over North Sea moving quickly Northeast. Trough of low pressure with occlusion extending from centre to Skegness to Birmingham to Cardiff at 1500 hours moving Southeast at 15 kt. Strong unstable Southwesterly airstream over area.
Surface Wind:	210-220 deg (true) speed 22-25 kt. Gusty with gusts reported 34-37 kt.
Weather:	Cloudy. Frequent showers of rain, moderate at times.
Visibility:	10-15 miles but 4-5 miles in showers.
Cloud: (Heights above ground level)	Variable Cu mainly 4/8-6/8 base 2000-2500 ft with occasional Cumulonimbus, base 1800 ft. In showers patches of Stratus base 1000 ft. Variable Sc., mainly 3/8-5/8 base 2500-3000 ft. No reported information on cloud tops but it is estimated that cloud tops would be above 6000 ft and in the case of large Cu and Cumulonimbus well above 10,000 ft. Little or no medium cloud. 7/8 Ci in the region 20,000 to 25,000 ft.
Surface temperature:	50 deg F. (Plus 10 deg C).
Surface Dew Point:	44 deg F. (Plus 6.7 deg C).
Wind at 2,500 ft:	230 deg (true) 55-60 kt.
Wind at 5,000 ft:	230 deg (true) 60-65 kt.
Temperature at 2,500 ft:	Plus 06 deg C.
Temperature at 5,000 ft:	Plus 01 deg C.
Freezing level:	5,500 ft.

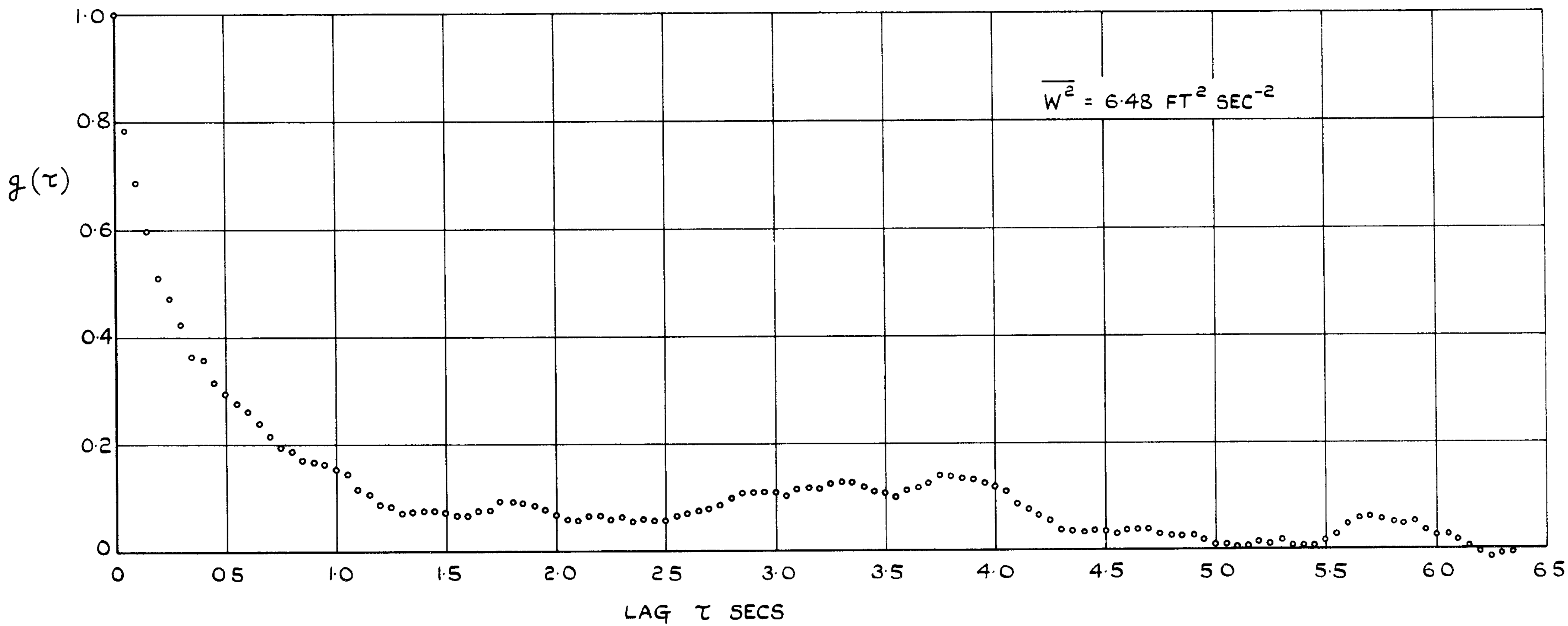

FIG.1. THE AUTO-CORRELATION FUNCTION, READING INTERVAL $\Delta t = 0{\cdot}05$ SECS.

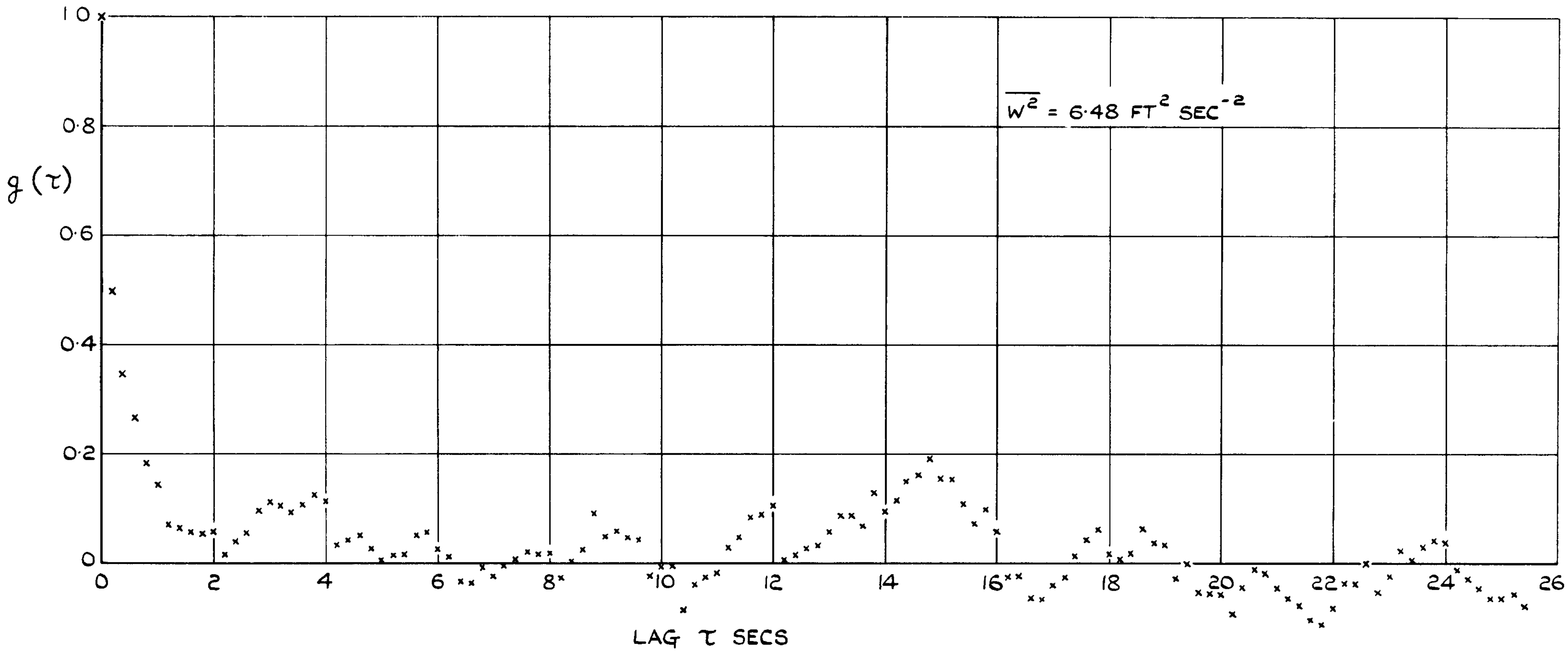

FIG. 2. THE AUTO-CORRELATION FUNCTION, READING INTERVAL $\Delta t = 0{\cdot}2$ SECS.

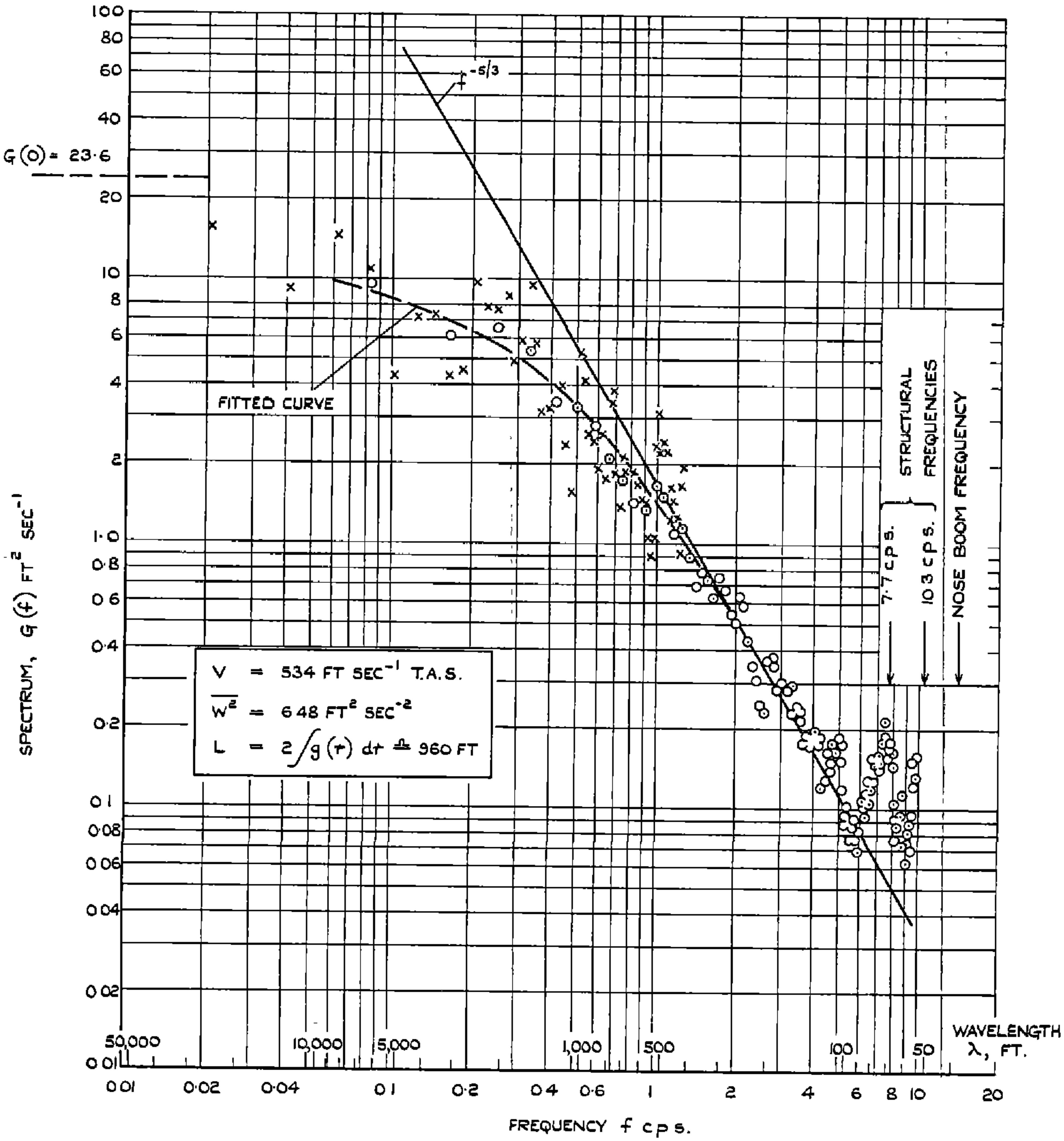

FIG. 3. THE MEASURED POWER SPECTRUM OF THE VERTICAL COMPONENT OF ATMOSPHERIC TURBULENCE.

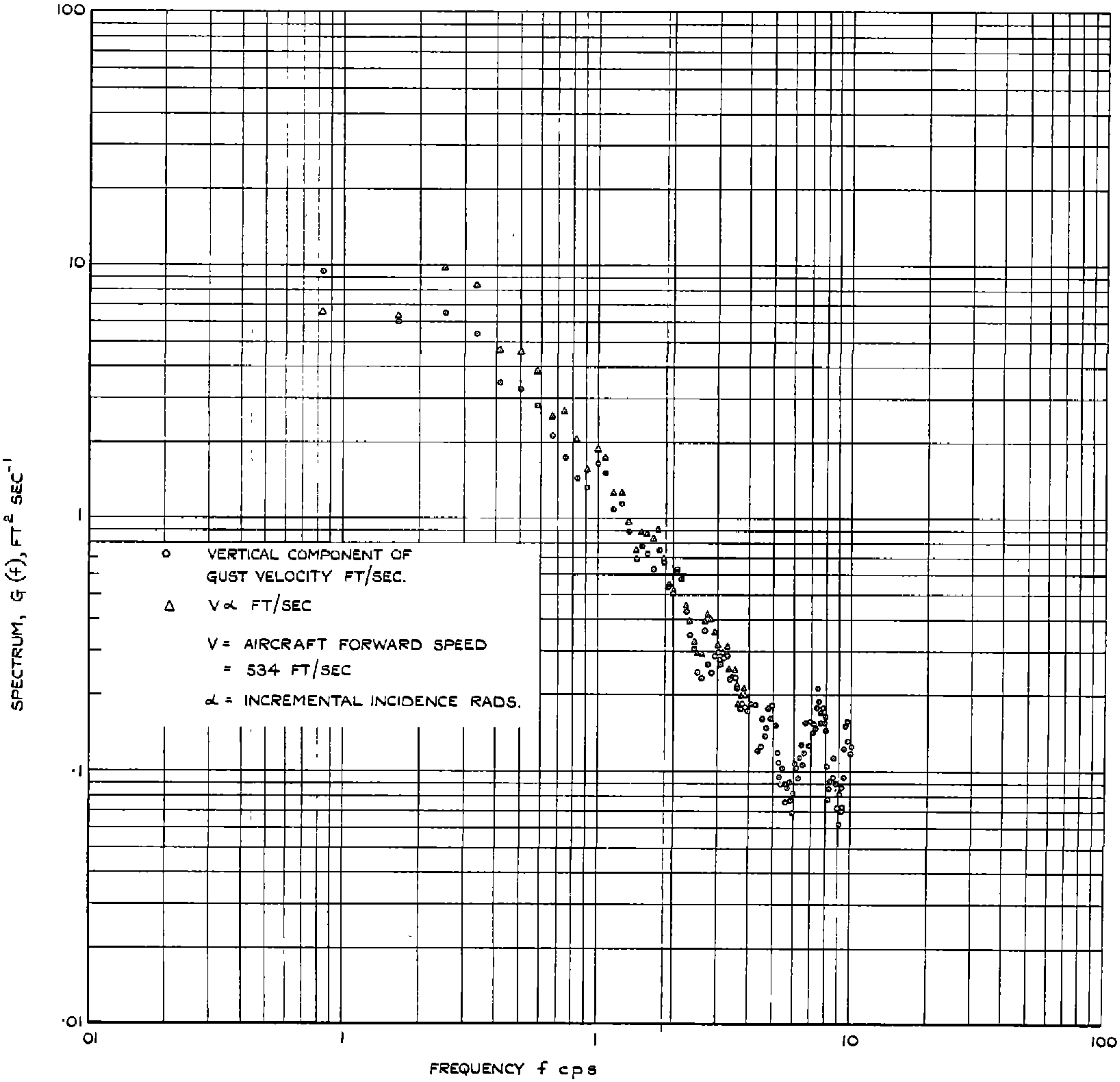

FIG. 4. COMPARISON OF UNCORRECTED AND CORRECTED-FOR-AIRCRAFT-MOTION SPECTRA.

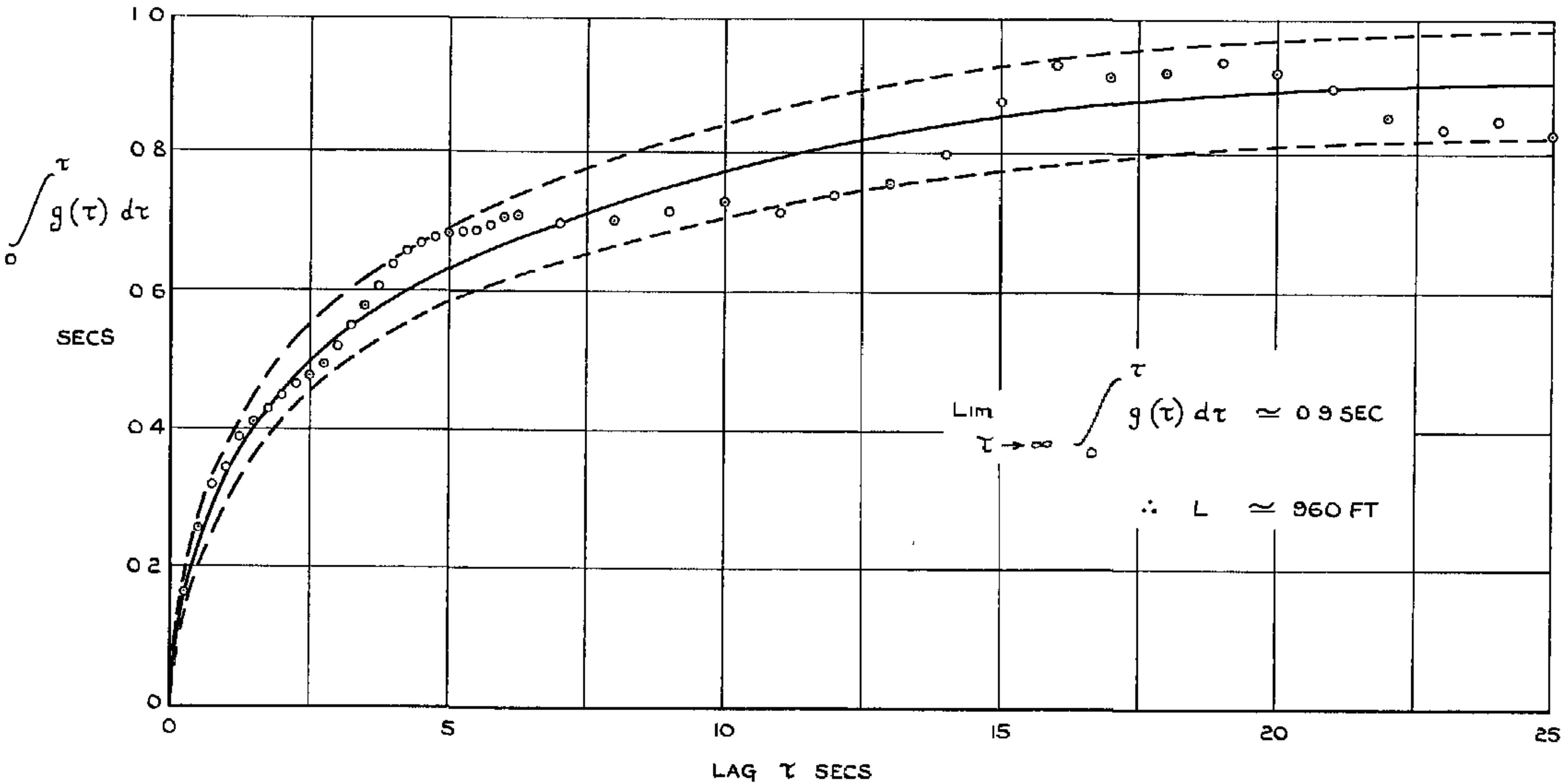

FIG. 5. THE INTEGRAL OF THE AUTO-CORRELATION FUNCTION UP TO TIME τ.

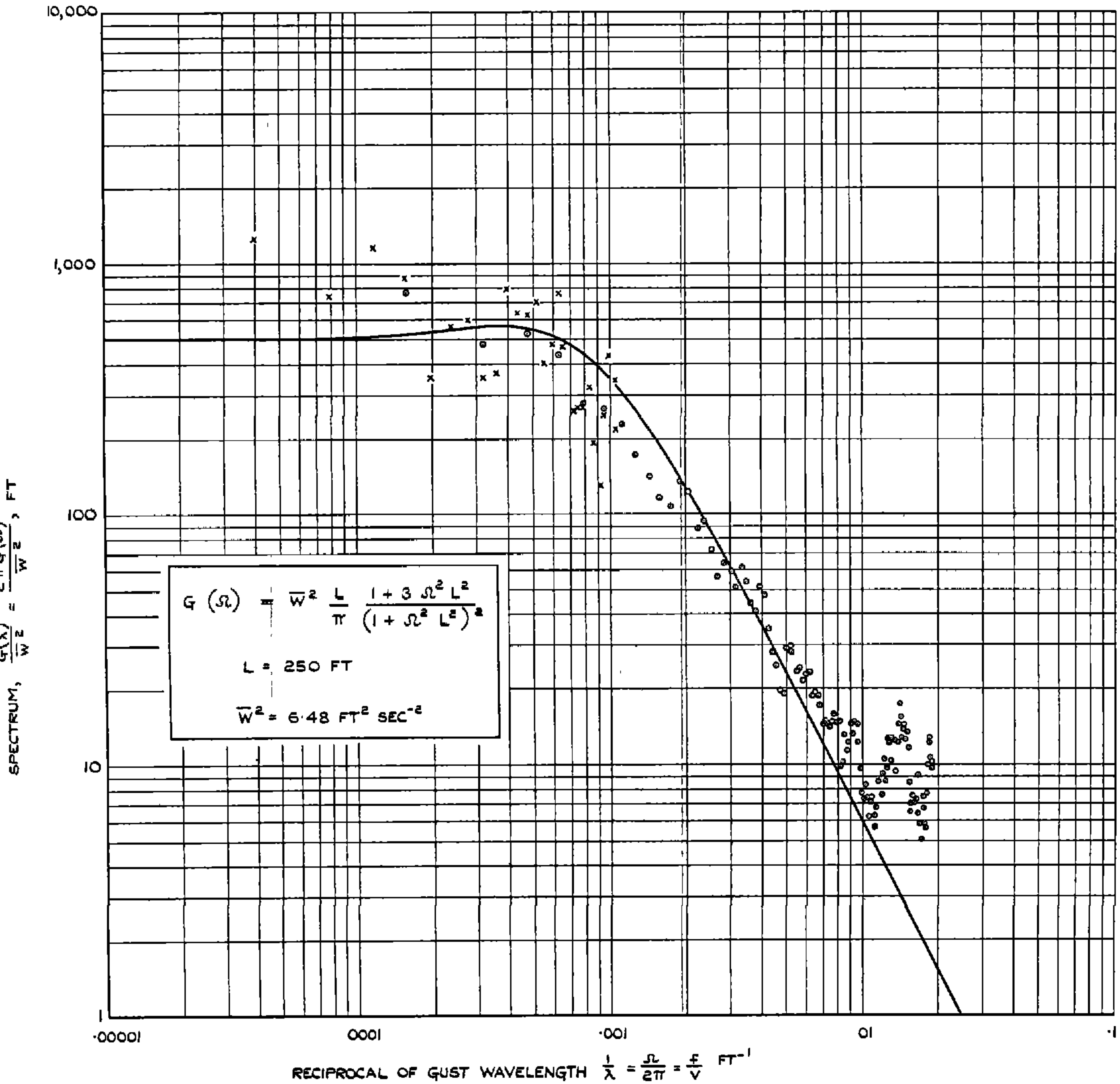

FIG. 6. FITTING OF ANALYTICAL EXPRESSION FOR G (Ω) TO THE EXPERIMENTAL POINTS.

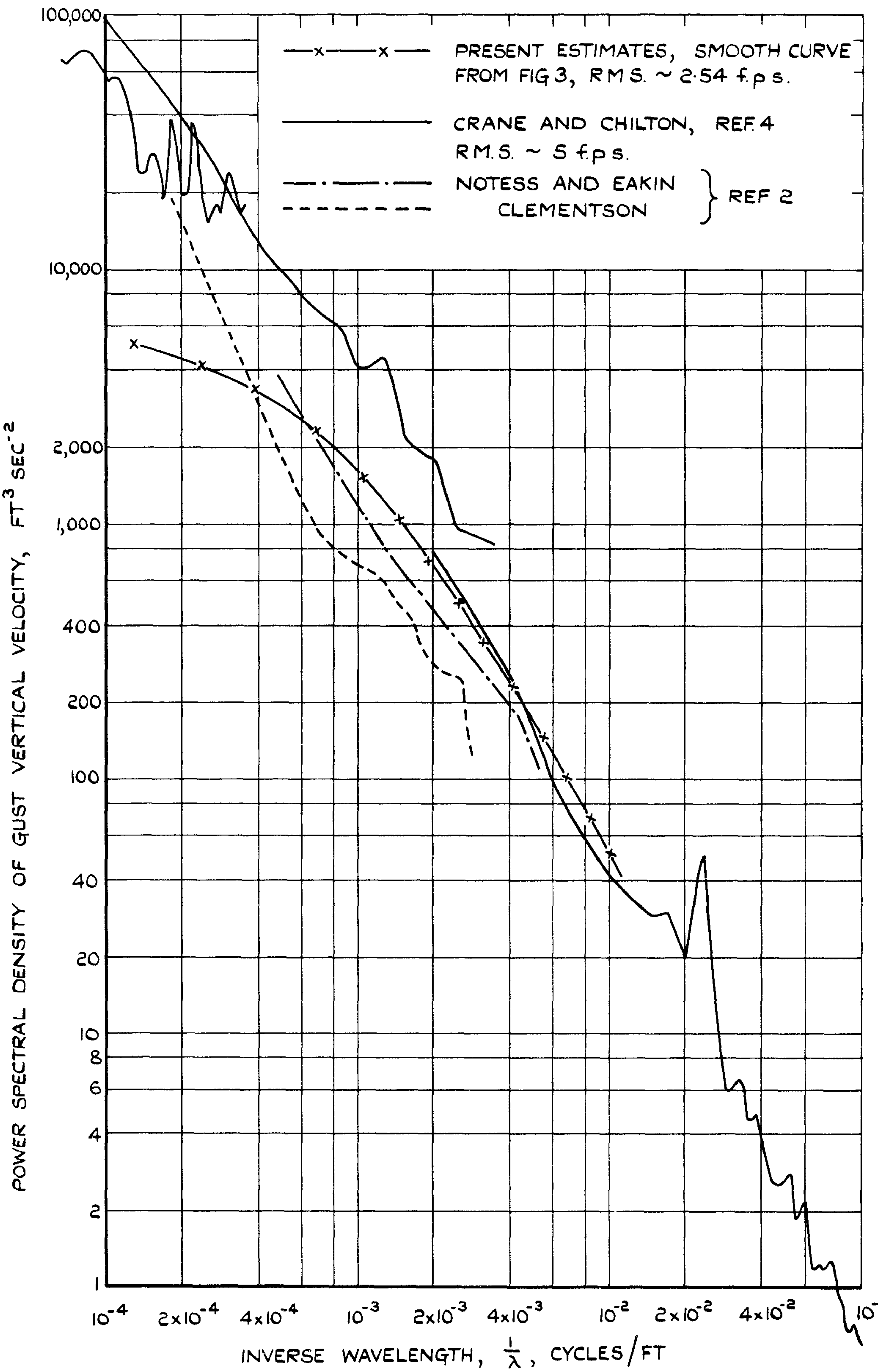

FIG. 7. COMPARISON OF MEASURED SPECTRA OF ATMOSPHERIC TURBULENCE.

DETACHABLE ABSTRACT CARDS

These abstract cards are inserted in Reports and Technical Notes for the convenience of Librarians and others who need to maintain an Information Index.

Detached cards are subject to the same Security Regulations as the parent document, and a record of their location should be made on the inside of the back cover of the parent document.

C.P. No. 522 — 629.13: 551.55

A MEASURED POWER SPECTRUM OF THE VERTICAL COMPONENT OF ATMOSPHERIC TURBULENCE. Zbrozek, J.K. and Ridland, D.M. March 1960.

An experimental study of aircraft response to turbulent air is being made using power spectrum methods. Consideration is given here to the spectral technique as applied to measurements of atmospheric turbulence and a number of theoretical relationships are quoted. The spectrum of the gust vertical velocity component obtained from the first sample of turbulence analysed is discussed. There appears to be a significant difference at long wavelengths between the present measurements and those available from the U.S.A. If this difference is substantiated by further measurements it will have a considerable effect on gust load predictions on large aircraft. This stresses the urgent need for more experimental data on atmospheric turbulence especially at long wavelengths.

C.P. No.522 — 629.13: 551.55

A MEASURED POWER SPECTRUM OF THE VERTICAL COMPONENT OF ATMOSPHERIC TURBULENCE. Zbrozek, J.K. and Ridland, D.M. March 1960.

An experimental study of aircraft response to turbulent air is being made using power spectrum methods. Consideration is given here to the spectral technique as applied to measurements of atmospheric turbulence and a number of theoretical relationships are quoted. The spectrum of the gust vertical velocity component obtained from the first sample of turbulence analysed is discussed. There appears to be a significant difference at long wavelengths between the present measurements and those available from the U.S.A. If this difference is substantiated by further measurements it will have a considerable effect on gust load predictions on large aircraft. This stresses the urgent need for more experimental data on atmospheric turbulence especially at long wavelengths.

C.P. No. 522 — 629.13: 551.55

A MEASURED POWER SPECTRUM OF THE VERTICAL COMPONENT OF ATMOSPHERIC TURBULENCE. Zbrozek, J.K. and Ridland, D.M. March 1960.

An experimental study of aircraft response to turbulent air is being made using power spectrum methods. Consideration is given here to the spectral technique as applied to measurements of atmospheric turbulence and a number of theoretical relationships are quoted. The spectrum of the gust vertical velocity component obtained from the first sample of turbulence analysed is discussed. There appears to be a significant difference at long wavelengths between the present measurements and those available from the U.S.A. If this difference is substantiated by further measurements it will have a considerable effect on gust load predictions on large aircraft. This stresses the urgent need for more experimental data on atmospheric turbulence especially at long wavelengths.

C.P. No. 522 — 629.13: 551.55

A MEASURED POWER SPECTRUM OF THE VERTICAL COMPONENT OF ATMOSPHERIC TURBULENCE. Zbrozek, J.K. and Ridland, D.M. March 1960.

An experimental study of aircraft response to turbulent air is being made using power spectrum methods. Consideration is given here to the spectral technique as applied to measurements of atmospheric turbulence and a number of theoretical relationships are quoted. The spectrum of the gust vertical velocity component obtained from the first sample of turbulence analysed is discussed. There appears to be a significant difference at long wavelengths between the present measurements and those available from the U.S.A. If this difference is substantiated by further measurements it will have a considerable effect on gust load predictions on large aircraft. This stresses the urgent need for more experimental data on atmospheric turbulence especially at long wavelengths.

C.P. No. 522
(21,875)
A.R.C. Technical Report

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London w.c.2
423 Oxford Street, London w.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast 1
or through any bookseller

Printed in England

S.O. Code No. 23-9012-22

C.P. No. 522