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Note on Conditions for which Data on the Power Spectra of Atmospheric Turbulence are required.

by

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Note on Conditions for which Data on the Power Spectra at Atmospheric Turbulence are Required*

- By -
J. K. Zbrozek and F. Pasquill

Introduction

Unfortunately, owing to the scanty information at present available on the effects of meteorological conditions on spectra, it has not proved possible to prepare precise specifications of the meteorological conditions for which gust-sampling records for power spectrum analysis are needed. What has therefore been done is to specify the height bands in which various components are required in the hope that this may be of some help to workers in the Commonwealth. When spectrum data are obtained they should be accompanied by a specification of the meteorological conditions to which they refer.

1. The Effect of Atmospheric Turbulence on Aircraft

There are many ways in which atmospheric turbulence affects aircraft design, two main ones being (i) stability and control, essentially at low speeds, take-off and landing only, (ii) static strength and fatigue life of the airframe. Another aspect of air turbulence, namely its effects on crew comfort, has recently been very seriously considered. This effect is specially predominant for low-altitude, high-speed flight.

In the past, the design of stability and control for landing and take-off conditions was based on past experience. It was known that if an aircraft can cope with some specified cross-wind, and has some minimum rate of roll, it should have satisfactory handling characteristics in turbulent air. With the advent of V.T.O.L. (Vertical Take-off and Landing) and S.T.O.L. (Slow Take-off and Landing) aircraft, and aircraft of very different dynamic characteristics, e.g. narrow deltas, the control design for low speed cannot be based on past experience. The structural design of the airframe is also based on the wealth of past experience, obtained by means of counting accelerometers and similar devices. This large-scale statistical information as obtained by U.K. aircraft in this country and overseas covers heights up to 25,000 ft, with some less reliable data up to heights of 34,000 ft. A limited number of U.S.A. measurements extend the height to above 50,000 ft.

Recent trends in aircraft design and performance have led to a preference for describing turbulence in terms of power spectra. Although this power spectral approach cannot as yet replace the single gust approach, it is absolutely essential in design studies, when optimisation for strength, passenger comfort or auto-stabilisation is required. The turbulence 'wavelengths' of interest to aircraft designers are very broadly indicated in Fig.1 as a function of altitude. The wavelength bands are split into those affecting longitudinal and lateral rigid airframe oscillations, and structural

oscillation./

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oscillation. The vertical component of air turbulence, which affects longitudinal and structural oscillations is by far the more important, except at very low altitudes (say 0 - 1,000 ft above ground) where the horizontal component might be the more important as it affects controllability during landing and take-off. It can be seen that the aircraft designer is interested in a very broad band of turbulence wavelength, ranging from 10 ft to 5,000 ft or even 10,000 ft.

2. Data and Ideas now Available on the Spectrum of Atmospheric Turbulence

Practically all the power spectra which have been evaluated so far refer to heights below 5,000 ft. Until recently those at a few thousand feet were determined specially for the assessment of gust 'loads' on aircraft and they were in fact based on measurements of the vertical acceleration undergone by aircraft in flight through turbulent air. However, techniques of measuring the actual air movement have been developed, using wind instruments mounted either on an aircraft or on a balloon cable, so that power spectra can now be evaluated directly, without the complication of computing the aircraft frequency response, though obviously allowance for the aircraft or balloon movement still needs to be made. Entirely different interests, concerned with the problems of atmospheric diffusion, have also stimulated the study of turbulence spectra. In this case attention has been mainly focussed on the first hundred feet or so above ground[3], which region can be examined from towers or masts, but the development of instruments for use on a barrage-balloon cable now makes it possible to obtain data at heights of several thousand feet.

It is known (e.g. Ref.1) that the spectra of the vertical component obtained from aircraft measurements exhibit a fairly common form, in which the 'power spectral density', $F(\Omega)$, decreases rapidly at relatively high values of Ω, the reduced angular frequency in radians/ft, (approximating in many cases to the theoretical variation for isotropic turbulence, i.e., $F(\Omega) \propto \Omega^{-5/3}$) In addition the position of maximum of the $\Omega F(\Omega)$ curves indicates that the 'scale' of turbulence is of the order of 1,000 ft.

Using discussions of the spectra from turbulence measurements at fixed points at lower levels have been given by Webb[2] and Panofsky[3]. In these cases the spectra are necessarily in terms of frequency n (cycles/sec), and to compare with reduced angular frequency spectra it is customary to use the transformation

$n = \frac{u}{2\pi} \times \Omega$, where u is the wind speed in the fixed-point measurements in ft/sec. Both discussions, and especially the latter, are particularly relevant in containing some attempt to generalise about the shapes of spectra. For the spectra of the vertical component there is an indication that the peak of the $nF(n)$ curve occurs at an equivalent wavelength u/n equal to about 3 times the height above ground, while the isotropic limit, beyond which the $F(n) \propto n^{-5/3}$ law may be expected to hold, is a wavelength approximating to the height above ground. This sort of generalisation needs to be looked upon with some reserve, especially as it is also clear that the thermal stability of the atmosphere affects the shape of the spectra, but it is a useful starting point. Furthermore, it is noteworthy that extrapolation to the height of the Crane and Chilton data[1], i.e. 1,700 ft, gives wavelengths which are fairly consistent with the power spectrum obtained by them.

These investigations at a height of 300 ft or less also include some attention to the other components of turbulence. The general trend is that the horizontal components have spectra which are of similar slope at high frequency but tend to contain relatively more energy at low frequency, to an extent which is probably systematically related to the stability of the atmosphere as described by the lapse rate and the vertical gradient of wind velocity.

No power spectra have been reported for heights greater than about 10,000 ft in the atmosphere.

3. Further Requirements in Power-Spectra Data

It is quite clear that a good deal more information is required before any really satisfactory generalisation on the power spectra of turbulence can be made. In particular a consolidation of the information at low level (0 - 1000 ft) is urgently required in connection with the V.T.O.L., S.T.O.L. and the design of low-altitude military aircraft. It is therefore suggested that records should be collected especially in the following conditions, for power spectrum analysis over a wavelength range 10 - 5000 ft, with priority in the order given:

(i) All 3 components at heights in the range 0 - 1000 ft, in as broad a range as possible of stability wind speed and surface roughness.

(ii) The horizontal and vertical components in high-altitude clear-air turbulence. There is a suspicion that the energy distribution in this kind of turbulence is very different from that of other kinds of turbulence.

(iii) Vertical component at medium altitudes, 10,000 to 25,000 ft, in a broad range of conditions, for correlating with counting accelerometer data.

(iv) Vertical component in the stratosphere, above, say, 35,000 ft.

The amount of data required depends largely on the extent to which some generalised form of spectrum can be supported by the observations. The sort of generalisation already hinted at, in which the spectrum is defined completely by a length scale and a R.M.S. value, would greatly simplify the whole process of obtaining, presenting and using the data. There are, of course, special cases which are not obviously best described in terms of power spectra, but for which some dynamical description is required. One such case which is of considerable importance is thunderstorm turbulence and it is therefore highly desirable that as much observation as is possible should be made of this type of turbulence.

References/

References

No.	Author(s)	Title, etc.
1	H. L. Crane and R. G. Chilton	Measurements of atmospheric turbulence over a wide range of wavelength for one meteorological condition. N.A.C.A. Technical Note 3702. June, 1956.
2	E. K. Webb	Autocorrelation and energy spectra of atmospheric turbulence. Division of Meteorological Physics Technical Paper No.5, C.S.I.R.O., Australia, 1955.
3	H. A. Panofsky and R. J. Deland	One-dimensional spectra of atmospheric turbulence in the lowest 100 metres. Proceedings of International Symposium on Atmospheric Diffusion and Air Pollution, Oxford, 1958. (To be published by the Academic Press).

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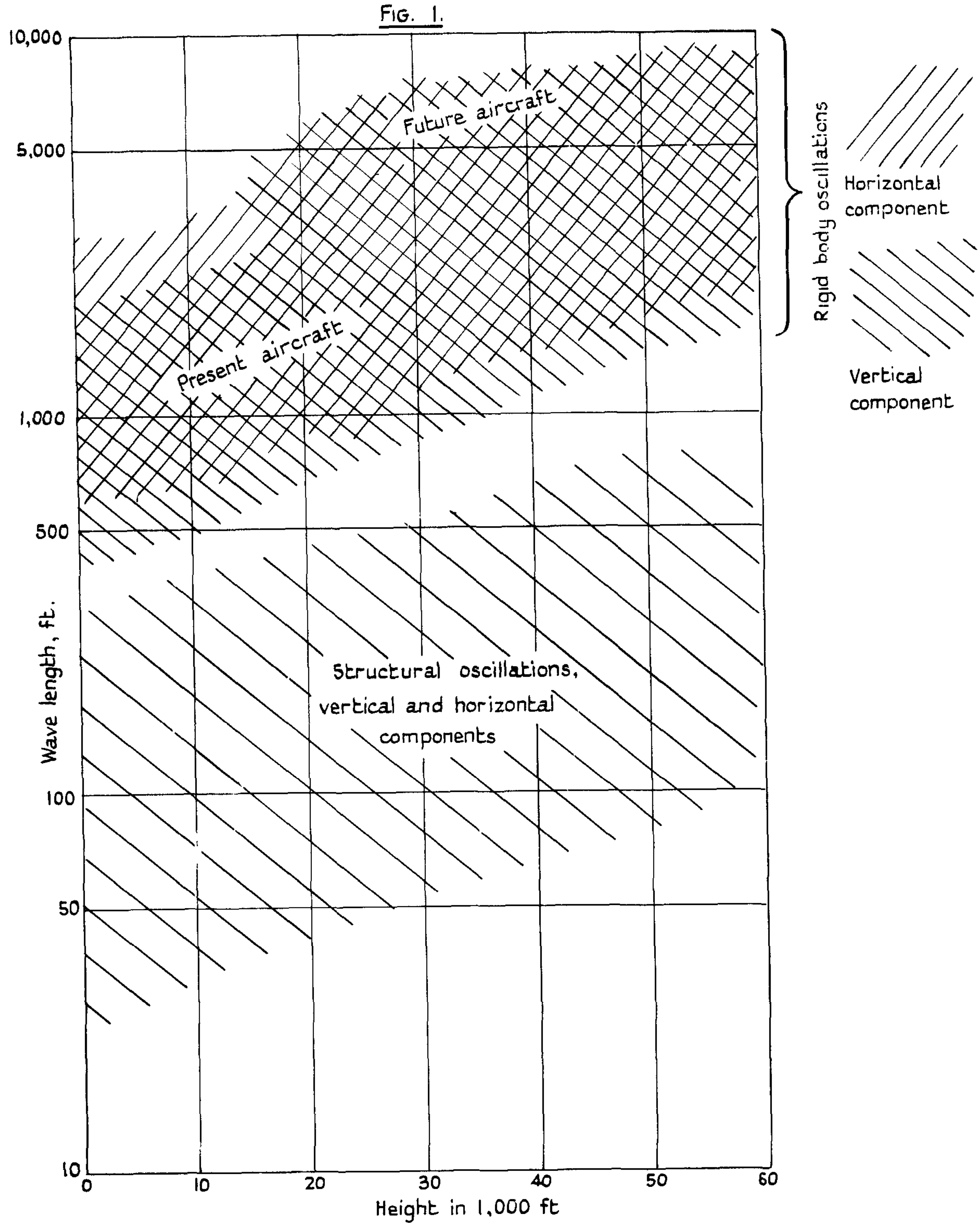
FIG. 1.



Wave length of atmospheric turbulence of interest to aircraft designer.

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