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Characteristics of atmospheric turbulence near the ground Part I: definitions and general information

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Item was monitored and guided by the following Working Party:

Dr K.J. Eaton	— Building Research Establishment
Mr R.I. Harris	— Cranfield Institute of Technology
Mr J.G. Jones	— Royal Aircraft Establishment
Mr T.V. Lawson	— University of Bristol
Mr J.F. Woods	— Royal Aircraft Establishment

on behalf of the Fluid Mechanics Steering Group which first met in 1970 and now has the following membership:

Chairman	
Mr T.V. Lawson	— University of Bristol
Members	
Mr K.C. Anthony	— Ove Arup and Partners
Mr E.C. Firman	— Central Electricity Research Laboratories
Mr B.H. Fisher	— Consulting Structural Engineer
Mr L.C. Hickman	— Kellogg International Corporation
Dr G. Hobson	— GEC Turbine Generators Ltd
Mr J.R.C. Pedersen	— Independent
Mr C. Scruton	— Independent
Mr N.G. Worley	— Babcock and Wilcox (Operations) Ltd.

The Item was accepted for inclusion in the Aerodynamics Sub-series by the Aerodynamics Committee which first met in 1942 and now has the following membership:

Chairman	
Mr E.C. Carter	— Aircraft Research Association
Vice-Chairman	
Prof. G.M. Lilley	— University of Southampton

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CHARACTERISTICS OF ATMOSPHERIC TURBULENCE NEAR THE GROUND PART I: DEFINITIONS AND GENERAL INFORMATION

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CHARACTERISTICS OF ATMOSPHERIC TURBULENCE NEAR THE GROUND PART I: DEFINITIONS AND GENERAL INFORMATION

1. NOTATION AND UNITS

		SI
$C_{ii}(\tau)$	autocovariance function, $\overline{i(t) \cdot i(t + \tau)}$ (Section 6.1)	m^2/s^2
$C_{ij}(\underline{r}, \underline{r}'; \tau)$	general cross-covariance function, $\overline{i(\underline{r}; t)j(\underline{r}'; t + \tau)}$ (Section 6.2)	m^2/s^2
$i(\underline{r}; t)$	general value of u, v or w gust component at point $\underline{r}$ and time t where $i = u, v$ or w	m/s
$j(\underline{r}'; t + \tau)$	general value of u, v or w gust component at point $\underline{r}'$ and time $t + \tau$ where $j = u, v$ or w	m/s
$\left. \begin{matrix} xL_i \\ yL_i \\ zL_i \end{matrix} \right\}$	length scales of turbulence of $i = u, v$ or w components measured along x, y and z axes respectively	m
n	frequency	Hz
$P; p(i)$	probability and probability density (see Section 4)	
$P_{ij}(\underline{r}, \underline{r}'; n)$	co-spectral function, in-phase component of $S_{ij}(\underline{r}, \underline{r}'; n)$	m^2/s
$Q_{ij}(\underline{r}, \underline{r}'; n)$	quad-spectral function, out-of-phase component of $S_{ij}(\underline{r}, \underline{r}'; n)$	m^2/s
$\underline{r}; \underline{r}'$	position vectors denoting points (x, y, z) and (x', y', z') respectively	
$S_{ii}(n)$	power spectral density function (Equation (7.3), Section 7.1)	m^2/s
$S_{ii}(\underline{r}, \underline{r}'; n)$	general cross-spectral density function (Section 7.2)	m^2/s
T	averaging time	s
T_i	time scales of u, v or w components	s
t	time	s

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$\left. \begin{matrix} u(t) \\ v(t) \\ w(t) \end{matrix} \right\}$	fluctuating components of wind speed along x , y and z axes respectively	m/s
$\bar{V}_z$	mean wind speed at height $\tilde{z}$	m/s
x, y, z	system of rectangular cartesian co-ordinates with x -axis defined in direction of mean wind	
$\tilde{z}$	effective height above ground	m
$\gamma_{ij}^2(\underline{r}, \underline{r}'; n)$	general coherence function (Equation (7.15))	
$\theta_{ij}(\underline{r}, \underline{r}'; n)$	phase shift angle (Equation (7.14))	rad
$\rho_{ii}(\tau)$	autocorrelation function, $C_{ii}(\tau)/\sigma_i^2$	
$\rho_{ij}(\underline{r}, \underline{r}'; \tau)$	general cross-correlation function, $C_{ij}(\underline{r}, \underline{r}'; \tau)/(\sigma_i \sigma_j)$	
σ_i	standard deviation of u , v or w component, $[\overline{i(t)^2}]^{1/2}$	m/s
Φ, Ψ	alternative spectral density functions (see Section 7.3)	
τ	incremental time lag	s
ω	circular frequency, $2\pi n$	rad/s
Suffixes		
i, j	refers to u , v or w component	
<i>A prime</i> (')	denotes a value at the point (x', y', z') .	
<i>A bar</i> ($\bar{}$)	denotes a value averaged over time T .	

The values in parentheses () after a functional symbol denote the dependent variables; e.g. $S_{ij}(\underline{r}, \underline{r}'; n) = S_{uu}(z, z'; n)$ is the frequency (n) dependent cross-spectral density of the u component of turbulence measured at points separated vertically.

2. INTRODUCTION

The purpose of this Item is to provide background information concerning a series of Items giving data on the properties of turbulence in the atmospheric boundary layer. Because atmospheric turbulence is continually changing in time and space it is necessary to describe its properties in statistical terms. This Item provides a definition of the parameters used and, where possible, an explanation of their physical significance. Further, more detailed, information on the mathematical aspects of statistical analysis can be found in standard text books on the subject such as References 2 and 5.

No attempt is made in this Item to explain in detail how the data are applied in practice since this will depend on the nature of the problem, of which there are many types. Reference 3 provides information on

how the data can be applied to particular cases of wind loading on ground-based structures and References 4 and 6 discuss appropriate means of applying the data to the study of aircraft response to atmospheric turbulence.

3. BACKGROUND

3.1 Origin of Turbulence in the Earth's Boundary Layer

At a considerable distance above the earth's surface wind is created, in the first instance, by differential heating of the atmosphere producing pressure gradients which are subsequently modified by the rotation of the earth.

As with the flow of any fluid over a surface, a boundary layer is formed over the earth's surface, called the atmospheric boundary layer, in which the wind speed decreases from a maximum value at the top of the layer to zero at the earth's surface. This reduction in velocity is due to both the frictional drag of the surfaces and the drag of all bodies protruding into the air flow (such as trees, mountains and buildings). These retarding forces are transmitted through the layer by shear forces (Reynolds stresses) and by the exchange of momentum due to the vertical movement of air. The process of momentum exchange between layers is the mechanism leading to the generation, and decay, of eddies termed turbulence. The resulting mixing of the air produces, along all three orthogonal axes, fluctuations in wind speed, commonly called gusts, which vary in size in both time and space.

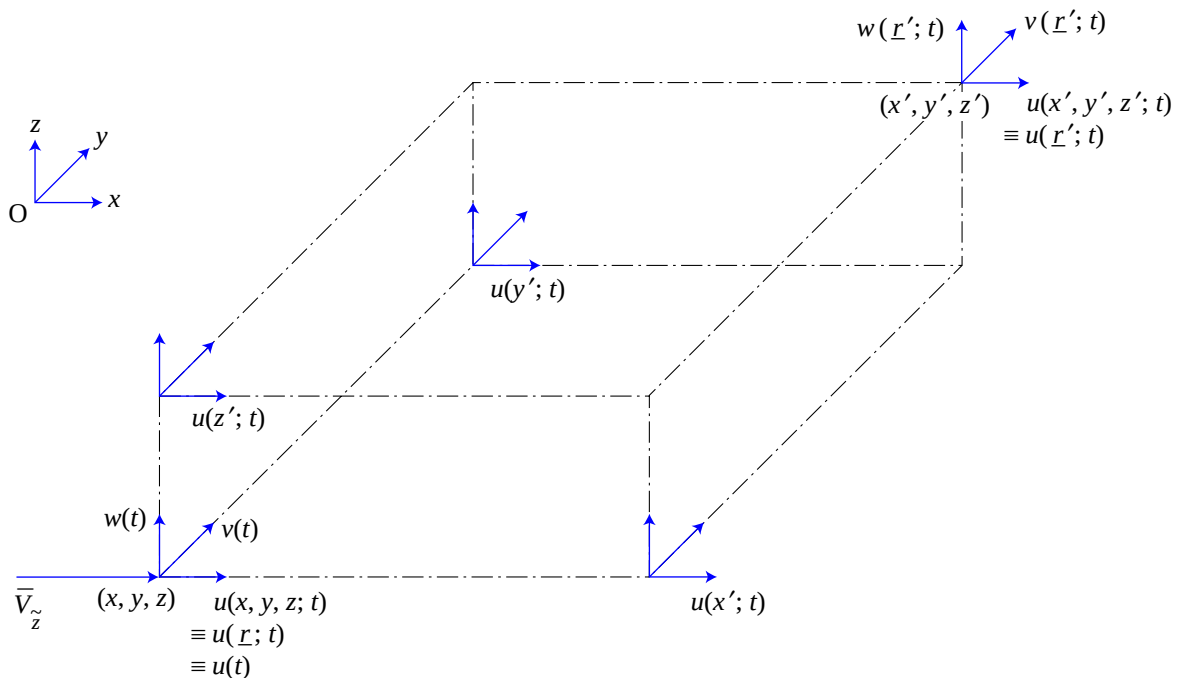
3.2 Significance of Turbulence

The necessity to consider the turbulent nature of the atmosphere arises for two separate reasons.

- (i) The points of separation and reattachment of the flow on bluff bodies are affected to a large extent by the turbulence in the approaching air stream and consequently the pressure in the wake of the body is also affected. Thus even the quasi-static forces and moments acting on a body can be appreciably influenced by the turbulence in the approaching air stream.
- (ii) Because of the variations of velocity in turbulence, dynamic forces, in addition to the quasi-static ones, are exerted on a body immersed in a turbulent flow. These fluctuating forces gain additional importance if the body is able to respond dynamically to the excitation. In the case of large structures in the atmosphere, it is not enough to know how the fluctuating velocities vary with time; the way they vary in space is also important. This means that a complete statistical description of the atmospheric wind is required.

3.3 The Turbulence Field

Consider the turbulence field as defined by Sketch 3.1. The flow is moving with a mean velocity $\bar{V}$ along the x -axis and $u(t)$, $v(t)$ and $w(t)$ are the instantaneous longitudinal, lateral and vertical components of fluctuating velocities.



Sketch 3.1

The mean of any gust component is zero since there is only mean motion in the x -direction. The flow velocity at any point in space is thus a vector quantity which has a magnitude and direction which both change rapidly with time. This vector quantity has a magnitude

$$\left[\{ \bar{V} + u(t) \}^2 + v^2(t) + w^2(t) \right]^{1/2} \quad (3.1)$$

where
$$\bar{V} = \frac{1}{T} \int_0^T V(t) dt. \quad (3.2)$$

The interval T is defined as the averaging time and the value of $\bar{V}$ defined by Equation (3.2) is called the value of wind speed averaged over time T . Ideally, T should be chosen large enough so that the same value of $\bar{V}$ would be calculated for any value of T larger than that chosen. In measurements in the atmosphere, due to the development or decay of weather systems or the passage of fronts, this ideal situation is rarely achieved. Many calculations of a quasi-static nature are performed using wind speeds averaged over short periods of the order of seconds.

The three gust components $u(t)$, $v(t)$ and $w(t)$ at a given point are random functions of time (t) and also vary in space as illustrated in Sketch 3.1. However, there is usually some interrelation between measurements of a gust component at a point taken at different time intervals and also between gust components measured at two points in space. The interrelation, or correlation, decreases as the time lag or separation distance between measurements increases.

It is for these reasons that in calculating, for example, the response of large structures in the wind it is necessary to take into account the correlation between gust components at difference points on the structure to allow for the non-uniform action of gusts in both a time and spatial sense. For ground-based structures the properties of the longitudinal component are the most important but the lateral component does