ON THE DETERMINATION OF BOUNDARY-LAYER
PARAMETERS USING VELOCITY PROFILE AS THE
SOLE INFORMATION

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Abstract. This paper proposes a numerical technique based on the 'least-square error method' for evaluating fluxes and other surface-layer parameters. The special feature of this method is that it requires no a-priori knowledge of either the temperature profile or the roughness length \( z_0 \). The accuracy of the method has been tested on both the Kansas and the Wangara experimental data. Results obtained compared favourably with those from direct measurements as well as from other studies using conventional approaches.

1. Introduction

Conventional methods for the evaluation of boundary-layer parameters \( u_*, \theta_*, L, \) etc. using either the flux-profile relationship or calculations of the stability functions require both wind and temperature profiles. Lo (1978) has recently developed a method for determining flux parameters in the absence of temperature profiles but the method requires specification of the surface roughness length \( z_0 \). A similar method was proposed by Klug (1967) with pre-specified value of \( z_0 \) which was incorporated in the boundary condition \( u(z_0) = 0 \). In Klug's study, KEYPS's flux-profile relationship was used and only those data for unstable stratification were examined.

A recent study by Nieuwstadt (1978) presented a least-square method to compute \( T_* \) and \( u_* \) using both wind and temperature profiles. The value of \( z_0 \) was determined later using a curve-fitting method over the measured wind data. Nieuwstadt found that the value of \( z_0 \) so determined was not very accurate and incorporation of the known roughness length into the approximation procedure improves the quality of the estimations. Similar findings are also seen from results of Ling (1976).

As an extension to the previous work, this paper presents a method which simultaneously determines the surface roughness length together with other boundary-layer parameters. The present method will be valid if either the wind or the temperature profile is absent. The added feature of being able to predict the surface roughness length is of special value for its application in the agricultural field. This is because for wind flow over a crop, the roughness length can vary over a fairly wide range depending on the interaction of the wind field with the underlying crops (Lo, 1977).
2. Theory and Governing Equations

The formulation of the present method is based on the similarity theory of Monin and Obukhov (1953, 1954) in which both wind and temperature profiles can be described as functions of a unique dimensionless variable, \( \zeta = z/L \), in addition to the scaling parameters \( u_\ast \) and \( T_\ast \). Based on similarity theory, the following equations for wind and temperature profiles can be derived:

\[
k \frac{U}{u_\ast} = f(\zeta) - f(\zeta_0) \tag{1}
\]

and

\[
k \left( \frac{\theta - \theta_0}{\theta_\ast} \right) = g(\zeta) - g(\zeta_0) \tag{2}
\]

where

\[
L = \frac{-\rho C_p \theta_0 u_\ast^3}{k g H} = \frac{\theta_0 u_\ast^2}{k g \theta_\ast}
\]

is the well known Monin–Obukhov length and \( H \) is the sensible heat flux. The value of \( L \) is determined from the flux-gradient relationship, which plays an important role in the surface layer since it relates the fluxes to the more easily measurable mean quantities. A comprehensive survey of existing flux-gradient relationships has been given by Yaglom (1977). A recent study by Lo and McBean (1978) compared three of the many widely-used forms of flux-gradient relationship. It was also recommended that the semi-empirical formulations of Businger, Wyngaard, Izumi and Bradley (1971 BWIB Model) seem to provide the best agreement with direct measurements and therefore, this model is employed for flux-profile calculations in the present study.

Under stable stratification, the empirical formulae of BWIB for the diabatic influence functions for the wind and temperature profiles vary linearly with \( \zeta \) over the stability range of their data, \( 0 < Z/L \leq 0.3 \)

\[
\phi_m = 1 + 4.7 \zeta \quad \text{for wind profile}
\]

and

\[
\phi_n = A (1 + 4.7 \zeta) \quad \text{for the temperature profile}
\]

where

\[
A = K_h / K_m \quad \text{is assumed to be a constant with empirical value of 0.74.}
\]

Then by virtue of the definition of the dimensionless wind shear, we have

\[
\phi_m = \frac{kz}{u_\ast} \frac{\partial U}{\partial z} = 1 + 4.7 \zeta.
\]