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Experimental Study Analyzing the Similarity Theory Formulations for the Effect of Aerodynamic Roughness Length on Turbulence Length Scales in the Atmospheric Surface Layer

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Abstract : Velocity fluctuations of shear-generated turbulence are largest in the atmospheric surface layer (ASL) of nominal 100 m depth, which can lead to dynamic effects such as galloping and flutter on small physical structures on the ground when the turbulence length scales and characteristic length of the physical structure are the same order of magnitude. Turbulence length scales are a measure of the average sizes of the energy-containing eddies that are widely estimated using two-point cross-correlation analysis to convert the temporal lag to a separation distance using Taylor's hypothesis that the convection velocity is equal to the mean velocity at the corresponding height. Profiles of turbulence length scales in the neutrally-stratified ASL, as predicted by Monin-Obukhov similarity theory in Engineering Sciences Data Unit (ESDU) 85020 for single-point data and ESDU 86010 for two-point correlations, are largely dependent on the aerodynamic roughness length. Field measurements have shown that longitudinal turbulence length scales show significant regional variation, whereas length scales of the vertical component show consistent Obukhov scaling from site to site because of the absence of low-frequency components. Hence, the objective of this experimental study is to compare the similarity theory relationships between the turbulence length scales and aerodynamic roughness length with those calculated using the autocorrelations and cross-correlations of field measurement velocity data at two sites: the Surface Layer Turbulence and Environmental Science Test (SLTEST) facility in a desert ASL in Dugway, Utah, USA and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) wind tower in a rural ASL in Jemalong, NSW, Australia. The results indicate that the longitudinal turbulence length scales increase with increasing aerodynamic roughness length, as opposed to the relationships derived by similarity theory correlations in ESDU models. However, the ratio of the turbulence length scales in the lateral and vertical directions to the longitudinal length scales is relatively independent of surface roughness, showing consistent inner-scaling between the two sites and the ESDU correlations. Further, the diurnal variation of wind velocity due to changes in atmospheric stability conditions has a significant effect on the turbulence structure of the energy-containing eddies in the lower ASL.

Keywords : aerodynamic roughness length, atmospheric surface layer, similarity theory, turbulence length scales
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