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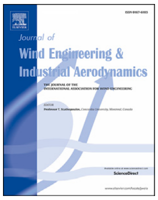

PRIME2: Development and evaluation of improved building downwash algorithms for rectangular and streamlined structures

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A R T I C L E I N F O

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A B S T R A C T

Theoretical flaws in PRIME (the building downwash formulation in AERMOD) have recently been documented. To improve PRIME, an industry funded research study was initiated with the following overall objectives: 1) correct the known problems in the theory; 2) incorporate and advance the current state of science; 3) expand the types of structures that can be accurately handled (e.g., streamlined, long, wide); 4) properly document and verify the model formulation and code for the updated PRIME (PRIME2); and 5) collaborate with EPA to work toward implementing the improved model. This paper presents the results from the wind tunnel study used to develop a database of wind speed and turbulence intensity measurements downwind of various rectangular and streamlined structures for three different approach turbulence conditions. Based on those measurements, new equations were developed to estimate the velocity deficit and turbulence intensity increase in the building wake as a function of downwind distance, height, building shape, and approach turbulence intensity. Comparisons of the new equations versus wind tunnel observations showed good agreement; whereas, the equations in PRIME do not agree well above the height of the building and show mixed agreement below the top of the building.

1. Introduction

In December of 2006, AERMOD (Cimorelli et al., 2005) officially became the EPA preferred model for regulatory dispersion modeling applications. The Plume Rise Model Enhancements (PRIME) algorithm in AERMOD incorporates enhanced plume dispersion due to the turbulent wake behind sharp-edged rectangular buildings and reduced plume rise due to descending streamlines behind these obstacles and entrainment of the plume in the building cavity. PRIME calculates fields of turbulence intensity and wind speed, as well as the local slope of the mean streamlines as a function of the building dimensions, which, coupled with a numerical plume rise model, determines the change in plume centerline location with downwind distance. Cimorelli et al. (2005) provides a brief description of PRIME and references Schulman et al. (2000) which is the only detailed documentation available on PRIME. No improvements to the downwash algorithms in PRIME have been made in more than 15 years since that original publication. Because building downwash often causes concentration predictions that exceed ambient standards, it is critical that these estimates be as accurate as possible. Recent field and wind tunnel studies (Petersen et al., 2017) have shown that AERMOD/PRIME can overpredict concentrations by factors of 2–8 for certain building types. On the other hand, for certain building and terrain configurations, AERMOD/PRIME can underpredict concentrations (Petersen et al., 2012).

Petersen et al. (2017) and Petersen (2015) documented several theoretical flaws in PRIME that likely account for the model overprediction tendency for certain building configurations. Based on this initial work, four industry groups funded a research study with the following overall objectives: 1) correct the known problems in the theory; 2) incorporate and advance the current state of science; 3) expand the types of structures that can be accurately handled (e.g., streamlined, long, wide); 4) properly document and verify the model formulation and code for the updated PRIME (PRIME2); and 5) collaborate with EPA to work toward implementing the improved model. The industry groups include the American Petroleum Institute, the Electric Power Research Institute, the Corn Refiners Association and the American Forest & Paper Association. The ultimate goal of the current research is to submit a fully operational version of AERMOD with improved building downwash algorithms in the near future.

To help advance this research, a PRIME2 subcommittee under the A&WMA APM committee was formed to: (1) establish a mechanism to review, approve and implement new science into the model for this and future improvements; and (2) provide a technical review forum to improve the PRIME building downwash algorithms. Collaboration and

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Table 1
Summary of buildings utilized in this research from the snyder database. Note that all buildings are rectangular solids and the assumed model scale is 1:200.

H(m)	H/W	W/L
40	2	1
40	1	4
40	4	1
40	1	2
40	10	1

Table 2
Summary of three full scale approach conditions simulated.

Roughness Configuration	z_o (cm)	i_{yo} (30 m) (%)	i_{zo} (30 m) (%)
1	2	10.1	6.9
2	25	22.2	14.4
3	100	29.2	18.6

Table 3
Full scale dimensions of rectangular buildings used for this study. Note that building 4 was only evaluated for $z_o = 25$ cm.

Building	H(m)	H/W	W/L
1	40	2	1
2	40	1	2
3	40	4	4
4	40	10	10

cooperation from the EPA Office of Research and Development (ORD) has been on-going during the research project with the expectation that the new model can be implemented in a more expeditious manner.

This paper presents the results from the wind tunnel study used to develop a database of wind speed and turbulence intensity measurements downwind of various solid and streamlined structures. Based on those measurements new equations were developed to estimate the velocity deficit and turbulence intensity increase in the building wake as a function of downwind distance, height, building shape, and approach turbulence intensity. These equations are ultimately used in PRIME to compute the horizontal and vertical dispersion coefficients and plume rise. Hence, by correcting these calculations, the plume rise and dispersion calculations will also be more accurate.

The new equations were added to the PRIME code and a new version of AERMOD was compiled that included the new enhanced theory (PRIME2). AERMOD/PRIME2 was then evaluated using methods recommended by EPA. That evaluation will be discussed in detail in a future paper.

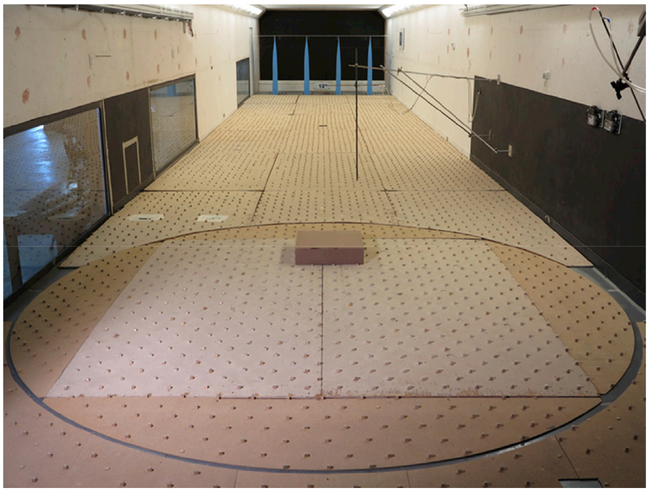

Fig. 2. Wind tunnel setup for building 3 and roughness Configuration 1.

Table 4
Full scale dimensions of streamlined buildings used for this study.

Building ID	H (m)	Top W and L (m)	Minimum W and L (m)	Height of Minimum W and L (m)	Bottom W and L (m)	Effective W and L (m)
CT	76.28	44.45	38.23	57.78	64.01	48.9
TK	50.41	81.43	81.43	NA	81.43	81.43

Table 5
Best fit constants for rectangular structures.

UDFAC = 0.294	SVFAC = 0.320	SWFAC = 0.290
$A_u = 0.500$	$A_{sv} = 0.700$	$A_{sw} = 0.650$
$n_u = 0.000$	$n_{sv} = 0.356$	$n_{sw} = 0.336$
$B_u = 3.494$	$B_{sv} = f(i_{yo})$	$B_{sw} = f(i_{zo})$
$r_u = 1.667$	$r_{sv} = f(i_{yo})$	$r_{sw} = f(i_{zo})$
LrUDfac = 1.135	LrSVfac = 1.349	LrSWfac = 1.794
HWminU = 0.449	HWminSV = 0.200	HWminSW = 0.375
HLminU = 0.753	HLminSV = 0.321	HLminSW = 0.308
HWmaxU = 3.000	HWmaxSV = 3.000	HWmaxSW = 3.000
HLmaxU = 3.000	HLmaxSV = 3.000	HLmaxSW = 3.000

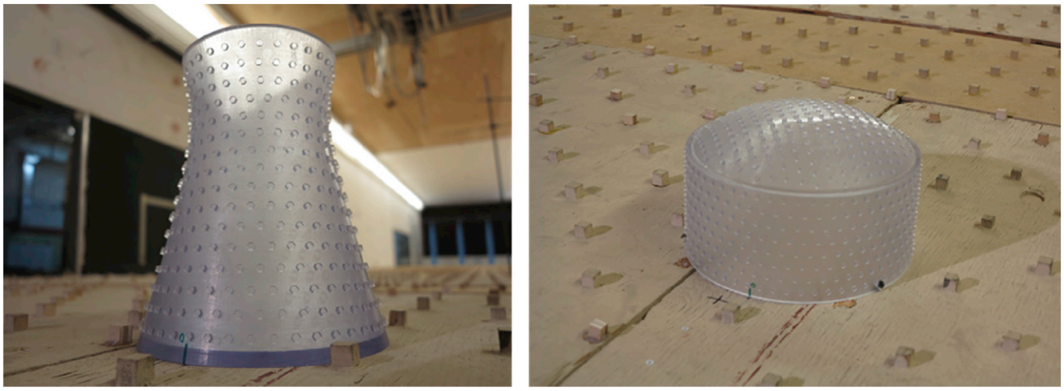

Fig. 1. Photographs of hyperbolic cooling tower and tank scale models.