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CFD analysis of topographic shielding effects on wind flow over ridge and plateau features

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SUMMARY

Accurate evaluation of topographic effects on wind is crucial for the estimation of wind loads on structures. Current building standards provide simplified guidelines for topographic effects, neglecting the interference effects caused by uneven terrain. This study investigates topographic speed-up over two-dimensional ridge and plateau models, utilizing computational fluid dynamics simulations. The investigation considers the impact of relative position, height, and width of the upstream topography on the downstream flow field. Results demonstrate that the presence of upstream topography generates a wake that interferes with the predominant wind field, notably reduces downstream wind speeds thereby creating shielding effects. The study further observed that the magnitude of the shielding effect is governed by both the relative position and the shape of upstream topography. These findings offer critical insights into the applicability of generalized shielding effects and provide a basis for assessing the validity of the provisions in the current wind loading standards.

Keywords: *Computational fluid dynamics (CFD), shielding effect, topographic simulation, topographic speed-up factor (TSF).*

1. INTRODUCTION

Wind patterns over mountainous terrain are strongly influenced by local topography, making it challenging to accurately estimate wind loads on buildings in these regions. A thorough understanding of these topographic effects, including flow acceleration, separation and turbulence generation, is essential to understand the resulting aerodynamic loads on buildings and to establish reliable design wind pressures that comply with modern building codes. The topographic effects on wind flow at a given site are not solely governed by the local topographic features but also the geometric characteristics of the surrounding terrain, such as its height, slope, feature spacing, and orientation with respect to the prevailing wind direction. These parameters define the complex wind environment contributing to the wind loads acting on built structures.

Because upwind terrain conditions critically influence the wind flow over downwind topography, building standard provisions specify when upwind topographic effects must be incorporated into the determination of design wind speeds. The American Society of Civil Engineers (ASCE) 7-16 Standard (ASCE, 2017) specifies that the influence of upwind topography on design wind speeds can be neglected if the height of the upstream topography exceeds one-third of the height of the downstream feature, with consideration limited to a distance of 3.22 km (2 miles) or 100H, whichever is less, where H is the height of the topographic feature. In a subsequent revision, ASCE 7-22 (ASCE, 2022), the criterion for shielding effects was removed, generally resulting in more conservative design wind speeds than those incorporating shielding.

Computational fluid dynamics (CFD) provides a more comprehensive evaluation methodology by numerically solving the Navier-Stokes equations to simulate wind flow over hilly terrain. CFD provides detailed flow structures, turbulence characteristics, and wind pressure distributions around various topographic features, enabling the topographic effects to be precisely quantified. The adoption of CFD-based analysis holds promise for refining topography-related provisions in future building design standards. Therefore, the objective of this study is to explore how upstream topographic features influence the wind field over downstream terrain using CFD simulations. More specifically, this study aims to compare how variations in the height and length of the upstream topographic model and its relative distance to the downstream model influence the resulting topographic flow modification. This analysis enables an evaluation of the design standards and identification of cases where assumptions in the standard provisions may misrepresent the actual topographic effects. The study further examines cases where the standard provisions do not capture the speedup effects observed in the CFD simulations as well as situations where terrain effects are present but result in speed-up factors less than unity.

2. METHODS

2.1. Computational fluid dynamics (CFD) simulations

The current study employs a steady Reynolds-Averaged Navier-Stokes (RANS) formulation within OpenFOAM version 7.0 (OpenFOAM, 2019) to simulate topographic effects on wind patterns over topographic models. The simulations are performed with the standard k-ε turbulence model in 2-D settings, which represent infinitely long topographic features in the lateral direction. The approach flow was generated using the body-force driven approach in a precursor domain, as presented in Hwang and Yeo (2023) and the obtained profiles are applied at the inlet of the main simulations with topographic models. The top boundary is set to a slip condition and wall functions are applied on the bottom wall. The inlet and outlet boundaries are located far enough from the topographic models such that the flow solution around the models is not influenced by the boundaries. The primary quantity of interest is the topographic speed-up factor (TSF), which is defined as the ratio of the wind speed with topography to the corresponding wind speed over flat terrain. TSF characterizes the modification of wind flow caused by topographic features, providing insight into how upstream topography influences the wind field over downstream topography. The simulation results for a representative case are validated against the wind tunnel experiments conducted in the Boundary Layer Wind Tunnel at the University of Florida (NIST Contract 1333ND19PNB730233; PIs: B. Phillips, F. Masters). After the validation of simulation settings, further simulations of wind flow over topographic features under various configurations were performed to investigate the sheltering effect of upstream topography.

2.2. Test case topographic models

The simulations in this study employed two topographic models characterizing a ridge and a plateau, as shown in Figure **1**. The shapes of both models are mathematically expressed by

$$z_{Ridge}(x) \quad = H_{Ridge}\cos^2\left(\frac{\pi}{W_{Ridge}}x\right) \qquad \text{for} \quad -0.5W_{Ridge} \leq x \leq 0.5W_{Ridge} \qquad (1)$$

and

$$z_{Plateau}(x) = \begin{cases} H_t \cos^2\left(\frac{\pi}{4H_t}x\right) & \text{for } -2H_t \le x \le 0 \\ H_t & \text{for } 0 \le x \le 4H_t \\ H_t \cos^2\left(\frac{\pi}{H_t}(x - 4H_t)\right) & \text{for } 4H_t \le x \le 4.5H_t \end{cases} \quad (2)$$

where H_{Ridge} and W_{Ridge} are the height and width of the ridge model, and $H_t = 155$ m is the height of the downstream plateau model at full scale, corresponding to a 0.05 m height at model scale with a length scale of 1:3100. The plateau consists of the shallow slope, the flat top, and the steep slope, which have lengths of $2H_t$, $4H_t$ and $0.5H_t$, respectively. H_{Ridge} and W_{Ridge} were varied to consider the effect of the upstream topography on flow over the downstream plateau. The distance between the upstream ridge and the downstream plateau was also varied to examine its influence.

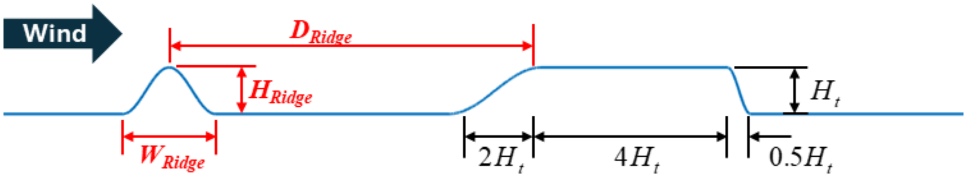

Figure 1: Topographic models of interest used in the current study: upstream ridge and downstream plateau features

In this study, various scenarios were considered across three major aspects of the upstream topographic feature: distance to the downstream topographic feature (D_{Ridge}), height (H_{Ridge}), and length (W_{Ridge}), as illustrated in Figure **1**. These factors are crucial in determining how upstream topography affects the wind field over downstream topographic features. In general, the distance between the upstream and downstream topography is the most straightforward and significant factor influencing downstream flow. As the distance increases, the shielding effect diminishes. The height and length of the upstream topography was examined in terms of how its shielding effects influence the flow over the downstream topographic feature. A tall, steep ridge can create significant wakes behind its crest, disturbing the downstream flow, while a short, shallow ridge might allow the flow to pass over it without flow separation. Because these parameters collectively affect the flow characteristics over the downstream topography, a systematic analysis of a wide range of test cases was performed to evaluate the contribution of each component to the resulting topographic flow.

3. RESULTS

Figure **2** depicts the variations in TSF as the distance between two models was increased, while the height and width of the upstream topography remained constant. The baseline case (top plot), representing no upstream topography (i.e., an infinite distance to an upstream obstacle), showed the undisturbed approach wind flow over the plateau model. This case results in a significantly higher TSF compared to shielded cases with upstream obstructions. Conversely, the lower three cases illustrate how the flow over the downstream plateau was influenced by the upstream ridge and its distance from the two topographic features. Significant topographic effects over the upstream ridge's crest remain identical across these three cases, as the flow field in this area is not influenced by the downstream plateau model. The wind speed at the ridge crest shows a significantly accelerated wind speed. Due to shielding by the ridge, however, the flow over the plateau model is notably influenced by the presence of the upstream topographic feature.

Since the shielding effect is determined not only by the relative position of the upstream model but also by various factors, including its shape, this study further investigates the effects of the upstream model's height and width. The comprehensive analysis provides a deeper insight into the general shielding behaviors of upstream topographic models and supports an evaluation of the current standard provisions for topographic effects on wind speeds.

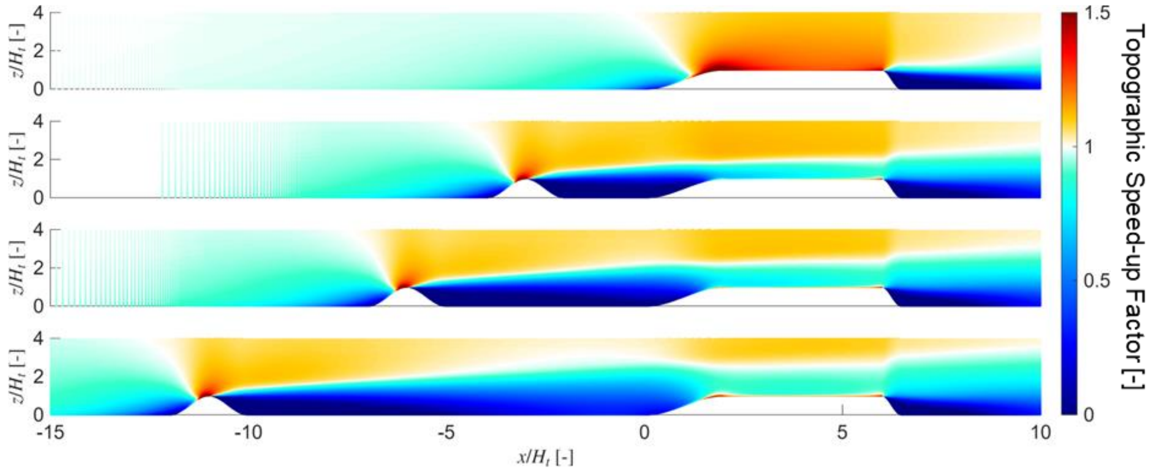

Figure 2: Distribution of TSF for four different topographic configurations with varying distance

DISCLAIMER

REFERENCES

American Society of Civil Engineers (ASCE), 2017. Minimum Design Loads and Associated Criteria for Buildings and Other Structures (7-16). ed., American Society of Civil Engineers.

American Society of Civil Engineers (ASCE), 2022. Minimum Design Loads and Associated Criteria for Buildings and Other Structures (7-22). ed., American Society of Civil Engineers.

Hwang, Y., Yeo, D., 2023. A Practical Computational Fluid Dynamics Approach for Structural Engineering: Simulation of Approach Flow with Reduced Blockage Ratios. National Institute of Standards and Technology (NIST), NIST Technical Note 2275.

OpenFOAM. 2019. The open source CFD toolbox: User guide (version 7). OpenFOAM Foundation.