

Comparison of RANS, LES and WT Measurements of Surface Pressures on an Irregular, Low-Rise Building

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Summary

Current design provisions for low-rise buildings are primarily focused on regularly-shaped buildings, in contrast to the complex geometries often in use, especially for housing. To address this gap, prior efforts through the Florida Coastal Monitoring Program (FCMP) recorded data on two full-scale houses during Hurricane Ivan, and separately physical wind tunnel testing at UWO provided companion model-scale data. This study extends this work by developing a high-fidelity Large Eddy Simulation of a wind tunnel for generating mean, peak, and spatially averaged wind-induced surface pressures on one of the FCMP houses (FL27). The study couples SimCenter WE-UQ pre-processing with OpenFOAM v10 execution on computing nodes provided by the Texas Advanced Computing Center (TACC). Synthetic DFM inflow profiles were developed to match target fluctuating components of velocity fields. Initially, steady $k-\omega$ RANS simulations to verify baseline parameters, after which LES (Smagorinsky SGS models) are run locally and then expanded to 20s time for four wind directions (0° , 45° , 90° , 120°). The overall objective of this initial study is to evaluate similarities and differences between the physical and numerical wind tunnel testing with respect to the measured surface pressures.

1 INTRODUCTION

Current wind load design provisions (e.g., ASCE 7) are primarily derived from model-scale wind tunnel testing of rectangular plan buildings with simple flat, hip, or gable roof shapes that may not fully capture the effects of complex roof geometry or the necessary scaling for wind tunnel testing. To address this gap, the Florida Coastal Monitoring Program (FCMP) recorded pressure time-history data on two actual houses during the landfall of Hurricane Ivan in 2004 (Liu et al., 2009). Subsequently, wind tunnel testing was performed by the University of Western Ontario on two of the house models, designated FL27 and FL30, to provide comparisons between full-scale and model-scale results (Kopp and Gavanski, 2010). This study expands on this work by developing and implementing a high-fidelity Large Eddy Simulation workflow for generating mean, peak, and spatially averaged wind-induced surface pressures on one FCMP house (FL27) and comparing the results to the WT data. The workflow is explicitly configured to enable direct comparison across point-based pressure measurements and across sheathing-sized tributary areas to evaluate practical implications of any differences. Steady-state Reynolds Averaged Navier Stokes (RANS) simulations were also conducted for initial validation studies of mean velocity fields and then expanded to high-fidelity LES models. The main objective of this initial study is to provide validation of the numerical simulations based on (i) comparison of mean velocity and turbulence-intensity profiles against wind-tunnel atmospheric boundary layer (ABL) data and (ii) systematic comparison of time-averaged mean, root-mean square (RMS), and peak roof pressure coefficients from RANS, LES, and physical wind tunnel measurements at individual tap locations and across representative sheathing panels. The overall goal is to advance our understanding of wind loads on complex roof geometries, and our understanding of the ability of current CFD workflows to match physical wind tunnel measurements.

2 METHODOLOGY

2.1 Background

The geometry was initially setup through the SimCenter WE-UQ platform (Deierlein et. al., 2020) and then simulated using OpenFOAM v10 to run directly on TACC High-Performance Computing (HPC) nodes. The framework is built around an FCMP house with complex irregular geometry modeled at 1:50 model scale under realistic suburban exposure conditions ($z_0 = 0.23m$) (Kopp and Gavinsky 2010). Atmospheric Boundary Layer (ABL) inlet conditions utilized in UWO Wind Tunnel (WT) experiments (Kopp and Gavanski, 2010) were replicated using a synthetic digital filter-based turbulent inflow technique adopted from WE-UQ resources.

2.2 Numerical Setup

Simcenter WE-UQ was primarily used to (i) define the scaled computational domain of $(75h * 25h * 20.45h)$, where h is the model scale mean roof height (4.23m in full-scale) of the building layout (shown in Figure 1); (ii) configure a Hex-mesh grid with four nested refinement boxes around the building and enforce refinements of the near-roof surface and edges; and (iii) develop synthetic inflow using Digital Filter Method (DFM) profiles to match WT experiments (Melaku and Bitsuamlak, 2024). The base mesh employs a maximum cell size of 0.1m in the far field regions, transitioning to a minimum of $7.87 * 10^{-4}$ m in the most refined regions.

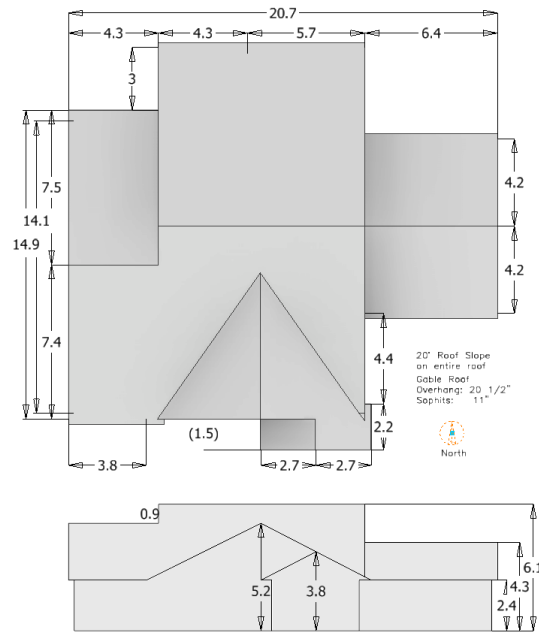


Figure 1: FL 27 Model Dimensions in Full Scale

A two-step turbulence modeling strategy was adopted. First, steady state $k - \omega$ RANS simulations were conducted to generate baseline velocity, turbulence and pressure fields and to verify mesh independence. Then, high-fidelity LES simulations were conducted for 2 seconds locally and then expanded to 20 seconds in HPC, with a time step of $4 * 10^{-5}$. Smagorinsky subgrid-scale modeling

was employed to resolve small eddies. The LES solver resolves the larger turbulence scales that govern vorticity formation and recirculation, while wall functions and Smagorinsky subgrid scale modeling handle the smaller scales. The high-fidelity LES simulations shall be repeated on HPC nodes for different angles of attack (0° , 45° , 90° and 120°) to quantify pressure fluctuations and interference effects.

2.3 Preliminary Results

Initial validation involves comparing the mean velocity and turbulence-intensity time averaged data extracted from the locally run CFD simulations at the planes close to the target location against wind-tunnel data for realistic inflow and terrain conditions. Figure 2 shows the mean velocity profiles normalized at 4m in full scale dimensions, along the proposed building location in an empty domain. Table 1 shows the inflow conditions for UWO WT data along with preliminary results from locally run LES simulations at the mean roof height in full-scale.

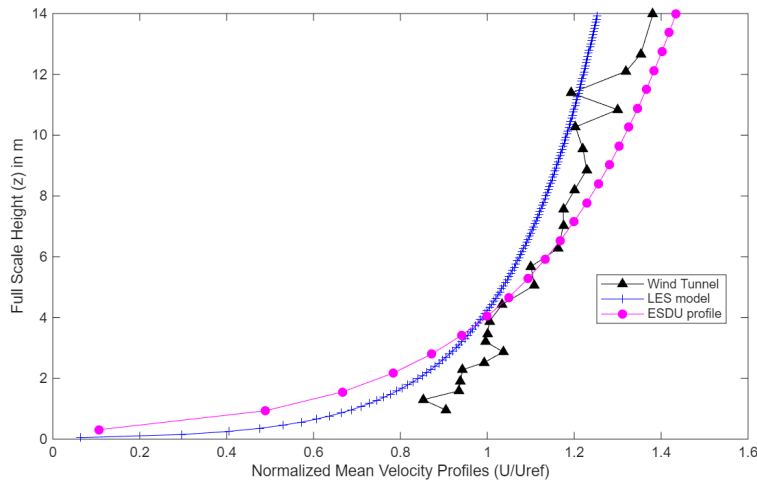


Figure 2: Full-scale Mean Velocity Profiles (Normalized at 4m)

Table 1: Inflow Conditions Comparison

Location	Roughness Length (full)(z_0)	Ref Velocity (model scale) (U_{ref})	Turbulence intensity (full) (T_i)
UWO WT	0.23m	8.02 m/s	28-30%
LES	0.23m	7.96 m/s	28.86%

Efforts are ongoing to complete the LES simulations and compare against the existing wind tunnel data. Comparisons will be made with standard visualizations of roof pressure distributions (mean, RMS and peak C_p) shall be generated for four wind directions, and pressure time series are sampled at virtual tap locations and sheathing-scale tributary areas ($1.22\text{m} \times 2.44\text{m}$ in full scale). These LES results are then systematically compared with both RANS predictions and WT measurements, enabling a three-way assessment of model performance.

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