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Axisymmetric LES CFD Modeling of a Microburst in a Closed-Circuit Simulator

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SUMMARY

An axisymmetric Large Eddy Simulation (LES) model has been developed and validated as a computationally efficient method to simulate microbursts. This model is used in the design of a proposed large-scale closed-circuit physical microburst simulator as part of the NEWRITE (National Testing Facility for Enhancing Wind Resiliency of Infrastructure in Tornado-Downburst-Gust Front Events) project. This axisymmetric model can provide reliable results in a short period of time and uses source terms to simulate the effects of the physical simulator's fans and flow conditioning devices such as honeycomb meshes. After validation, the model was used to assess transient nature and different parameters of the NEWRITE simulator including the effects of the height, floor roughness and simulator geometry on the overall flow structure within the test chamber. Good agreement with velocity and pressure profiles from reference studies is achieved.

Keywords: *Computational Fluid Dynamics, Microbursts, Wind Engineering*

1. INTRODUCTION

Downbursts are transient, strong downward flows that produce an outburst of damaging winds. They are classified as microbursts, which have extents of damaging winds less than four kilometres and macrobursts which exceed this mark (Fujita, 1985). Research on downbursts has focused on three main areas: field studies, laboratory experimentation, and Computational Fluid Dynamics (CFD). Field studies paved the way for various researchers to conduct laboratory experimentation to simulate downbursts and study their flow structure in a controlled setting. However, much like with field studies, the laboratory experimentation requires major funding and physical resources. Selvam & Holmes (1992) were involved in early efforts to successfully simulate downbursts computationally. Since then, researchers have built upon this body of knowledge by conducting various CFD studies on microbursts. Due to limitations of both laboratory experimentation and CFD studies, they should be used in tandem to help increase our understanding of microbursts.

Researchers from eight Universities across the Unites States of America are working together to develop a large-scale physical simulator as part of the NEWRITE (National Testing Facility for Enhancing Wind Resiliency of Infrastructure in Tornado-Downburst-Gust Front Events) project under funding from the National Science Foundation (*NSF Award Search: Award # 2330150*, 2023). Once built, it will one of the larger testing facilities capable of accommodating testing of building and other structural models under the effect of extreme winds such as simulated tornadoes, downbursts, and gusts (up to 1:3 scale). CFD is currently being used in the design process to ensure that the facility will function efficiently and effectively. Initially, a 3D RANS model was developed in OpenFOAM, however this model possessed certain deficiencies such as the inability to capture the transient nature of microbursts, among others. Thus, a different approach has been taken, and an axisymmetric LES model has been developed to provide reliable results in a shorter period and encompass the proper simulation of the effects of the closed-circuit and transient nature of the proposed simulator as well as the fans and flow conditioning devices.

1.1. Motivation and Objectives

This study focusses on testing the performance of the proposed NEWRITE simulator in microburst mode using an experimentally validated axisymmetric LES model. The typical height-to-diameter (H/D) value of a microburst in the field is anywhere from 0.75 to 7.5 (Sengupta & Sarkar, 2008). In the case of a large-scale simulator such as the proposed NEWRITE facility, choosing an adequate H/D is of utmost importance as any increase in height will exponentially increase the overall construction and operating costs. Secondly, the effect of the roughness of the floor of the facility is examined by varying the roughness length (Z_o). This study aims to (i) validate the in-house axisymmetric CFD program against reference studies, (ii) investigate the transient nature of the simulator on flow generation, (iii) determine an optimum minimum H/D ratio that would allow for balance between accurate microburst simulation and feasible project cost, (iv) investigate the influence of the roughness of the ground plane on the overall flow structure of a microburst, and (v) visualize and analyze patterns found in the general flow structure within the test chamber and auxiliary sections of the proposed physical simulator.

2. METHODOLOGY

The in-house axisymmetric LES microburst model was developed according to the general details provided here. The LES was developed according to details provided in Verma & Selvam (2021) and Selvam (2022). More details on model development will be provided in the full length-paper. The simulation run times in general for the different cases were 50 seconds and the code runtime was approximately four hours per simulation on a personal computer under the Linux Environment. A source term was introduced to simulate the effects of the simulator's fans. Equations were used to introduce source terms for the simulation of flow conditioning devices such as screens and honeycomb meshes. The developed model was then tested by recreating the physical study conducted on microbursts by Sengupta & Sarkar (2008).

Once satisfactory agreement to the reference data was reached, the in-house model was then applied to the proposed NEWRITE Design Concept 11.10 in microburst mode. More details on the validation will be provided in the full-length paper. The NEWRITE DC 11.10 was then modified to have three different Height to Diameter (H/D) ratios and simulations were run. The information from these runs was used to study the influence of the H/D ratio on the flow generation and structure. Later, using the best performing H/D ratio, the effect of the roughness of the floor of the facility was examined by varying the roughness length (Z_o). *Figure 1* shows a schematic of the NEWRITE simulator, as cut through the X-Z plane. This 2D cut was split at the axis of symmetry and the right-hand half was used for the axisymmetric LES simulation. Approximately 26,000 grid points in total were used for the model.

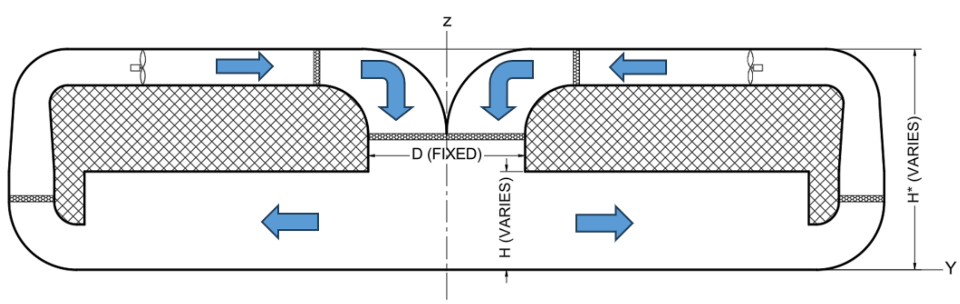
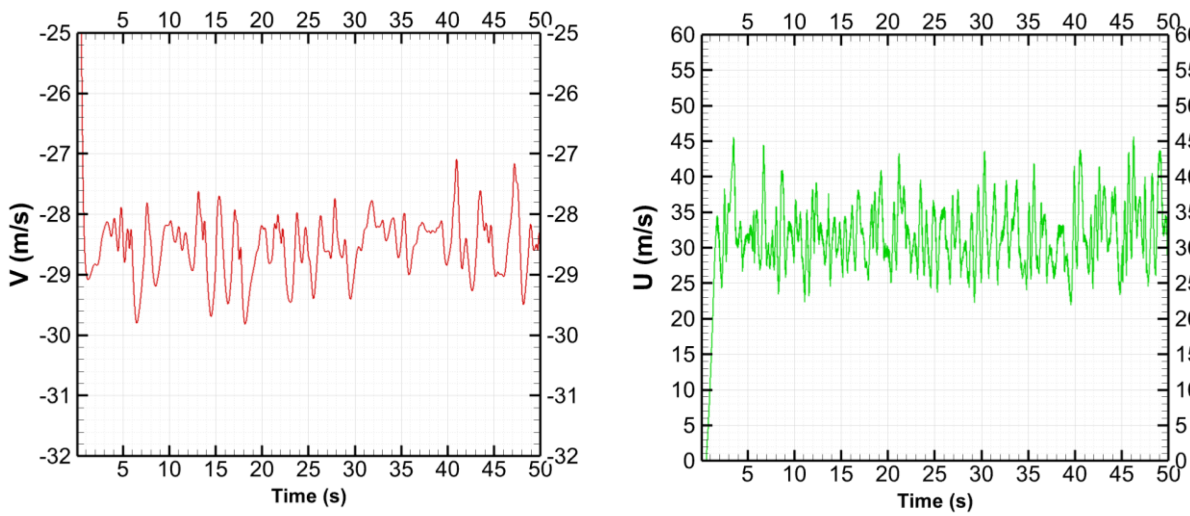


Figure 1: 2D schematic of the NEWRITE simulator, as cut through the X-Z plane

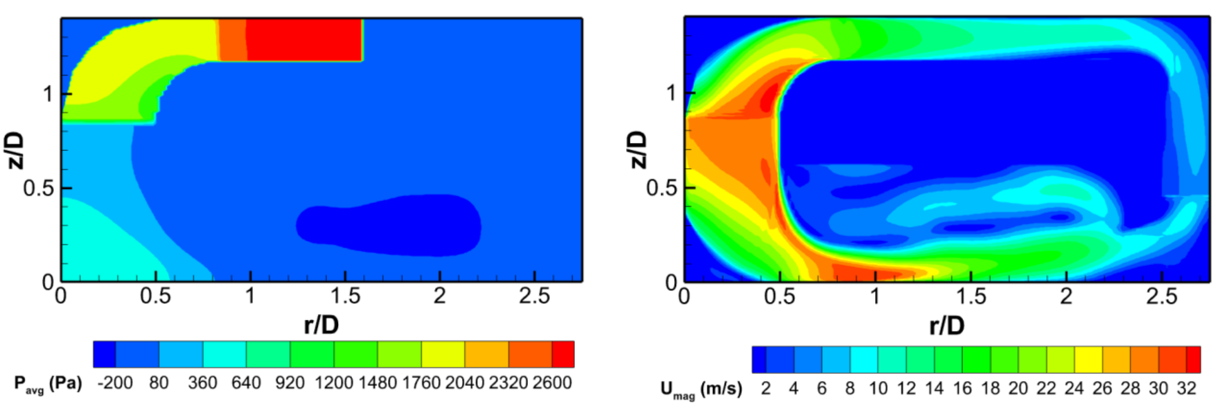
3. RESULTS

The validation of the axisymmetric LES model will be presented in the full-length paper. The velocity variation and pressure and velocity magnitude contour plots for the H/D=0.625 are presented here as seen in *Figures 2* and *3 below*. The plots for the other two H/D cases (0.750, and 1.00) will be presented in the full-length paper. *Figure 4* shows the absolute radial velocity profiles for the H/D=1.00 configuration at 0.50D, 1.00D, and 1.50D, respectively, and the normalized radial velocity profiles at 1.00D for different roughness lengths. A more in-depth analysis of the effect of the roughness length will be presented. Finally, results of the flow structure for all cases, including vector plots, and highlighting areas of flow separation will be presented. This helps inform on how the simulator design can be improved to be more efficient.



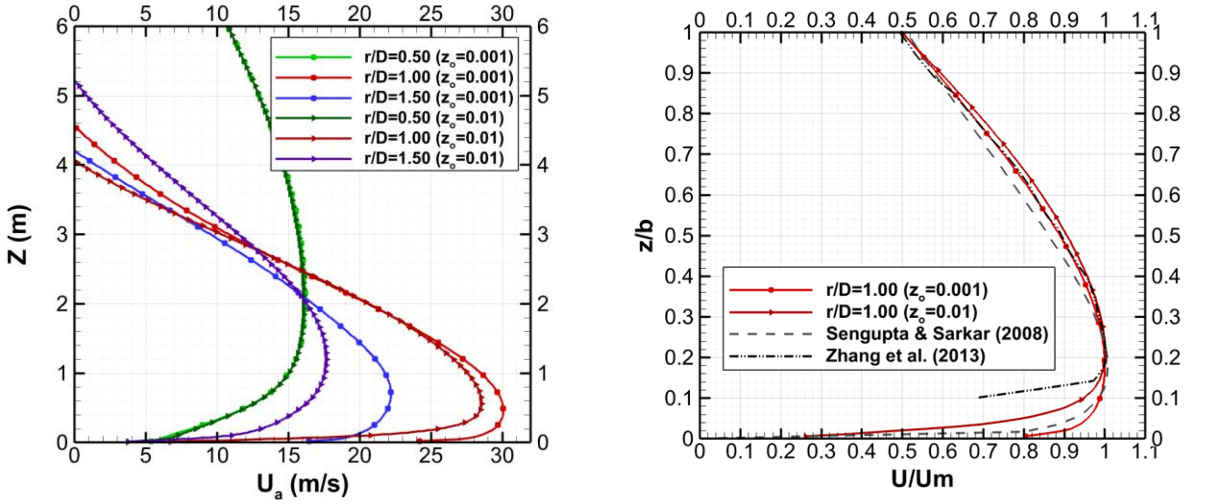
(a) **(b)**

Figure 2: Demonstration of transient flow: **(a)** velocity (V) variation at a point on the nozzle outlet, and **(b)** velocity (U) variation at a point one diameter distance from the center of the jet



(a) **(b)**

Figure 3: H/D=0.625 Contour Plots: **(a)** average pressure (P_{avg}) in the domain, and **(b)** velocity magnitude (U_{mag}) in the domain



(a) **(b)**

Figure 4: Radial Velocity Profiles for the H/D=1.00 configuration: **(a)** absolute profiles at 0.50D, 1.00D, and 1.50D, respectively, and **(b)** normalized profiles at 1.00D

4. CONCLUSIONS

The developed in-house axisymmetric LES model for simulating microbursts was successfully validated against a benchmark study. The transient nature of the proposed NEWRITE simulator was demonstrated and analyzed. It was demonstrated that that it is possible to use lower H/D ratios with the aim of reducing the overall project cost. However, this is not without some limitations. The reduction of the roughness of the floor greatly impacted the height of the maximum horizontal velocity. No effect was observed close to the jet and this effect increased exponentially as the horizontal distance increased. The general flow structure was examined, and this gave good insight into microburst formation that may not be available from physical experimentation.

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