CFD Analysis of the Mitigation of Aerodynamic Uplift Loads Using Roof Integrated Wind Turbines for Reduced Wind Damage and Power Supply Production

FIU Engineering & Computing
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OURS Opportunities for Undergraduate Research and Scholarship

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Abstract

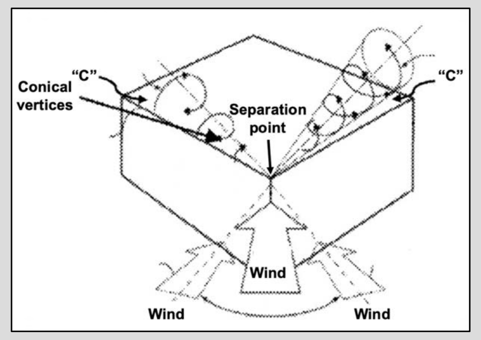
The extreme winds found in tropical storms and hurricanes continually threaten the coastal areas of the United States and often cause damage due to high wind uplift forces concentrating on the roof corners and edges of buildings.

The specific objectives of this study are:

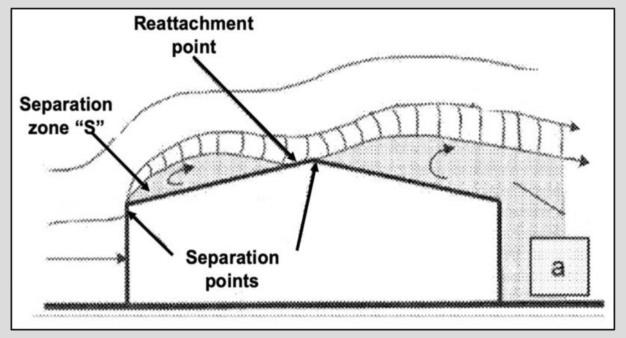
- Applying a mitigation strategy in the form of an Aerodynamic Mitigation and Power System (AMPS) [1].
- Creating a horizontal axis wind turbine that shall be integrated to roof edges to reduce wind damage and supply power to buildings.
- Optimizing the computational fluid dynamics (CFD) analysis setup in regards to test setup and mesh parameters for Case 1.

Introduction

Challenges

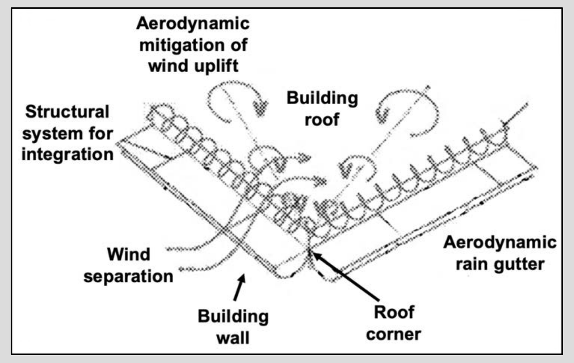


Conical vortices formed across a roof caused by diagonal winds [2]



Separation zone "S" made by wind separation and reattachment points on a sloped roof line [2]

Resolution



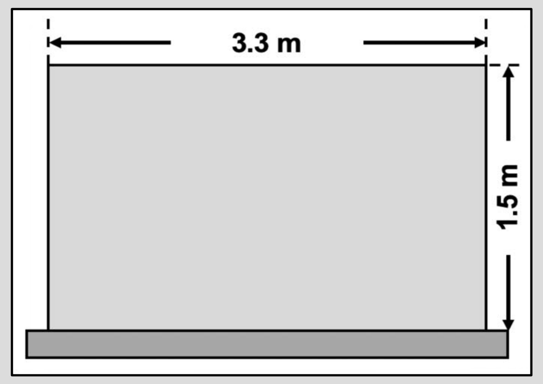
Active AMPS invention that can mitigate wind-induced suction [2]

Taken Approach

- Design a scaled-down turbine and building using SolidWorks per Chowdhury et. al. [1]
- Conduct CFD analysis in order to optimize the test setup and mesh parameters of Case 1 via ANSYS Fluent

Objective

To minimize the number of elements and nodes while simultaneously generating consistent and accurate results

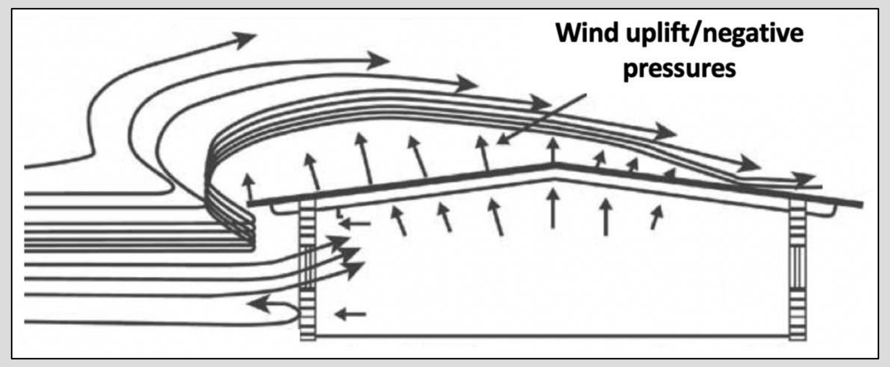


Case 1 – a bare deck [1]

Background

Low-rise Buildings Suffer Wind-induced Damage

- Coastal areas in the United States are prone to hurricanes with wind speeds exceeding 150 mph [1].
- Low-rise building are susceptible to wind damage due to high wind-induced suction and roof uplift [2].



Low-rise building roofs experiencing high wind-induced damage due to negative pressures

Mitigation Devices Diminish Negative Wind Effects

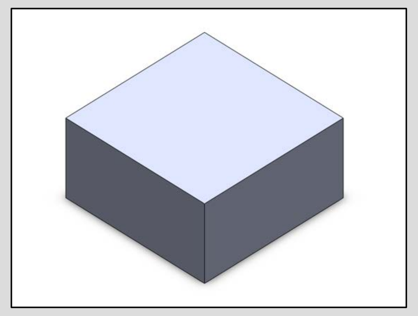
- Surry and Lin found that porous parapets placed at the building edge can substantially reduce roof suctions [1].
- Suaris and Irwin applied perforated parapets at roof corners which resulted in a 60% peak pressure coefficient reduction [1].
- Blessing et al. discovered two different aerodynamic edge shapes that generated a reduction in wind-induced loads on the building using Florida International University's Wall of Winds Experimental Facility [3].

CFD Analysis of AMPS Device

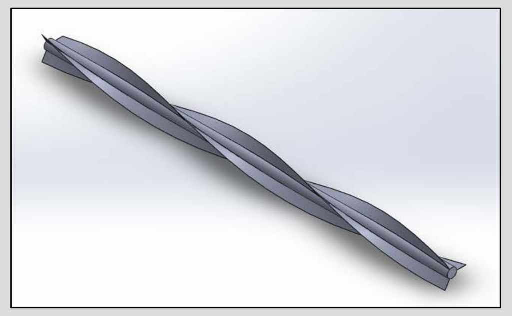
Shall optimize CFD test setup and mesh of the new AMPS technology's Case 1 in order to mitigate the aerodynamic uplift loads using roof integrated wind turbines for reduced wind damage and power supply production

Procedure

Modeling of Building using SolidWorks



329-mm wide and 153-mm high square building



329-mm long turbine with a 22.9-mm outer diameter

Parameters for CFD Analysis using ANSYS Fluent

Test Type	k-epsilon
Velocity	75 m/s

Procedure Cont.

CFD Optimization Process

Number of Iterations

Ran tests with consistent parameters ranging from 30-2,000 iterations

↓

Chose iteration that produced steady-state convergence through pressure and velocity difference graphs

Mesh Parameters

Tested 5 distinct mesh parameters upon the top, right, and front plane ⇨ Chose the optimized mesh of the 5 initial setups

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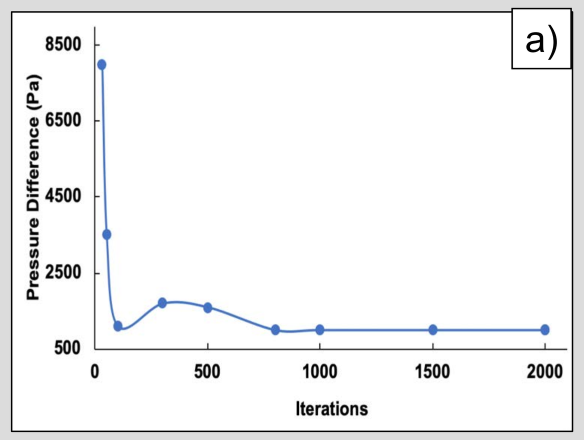
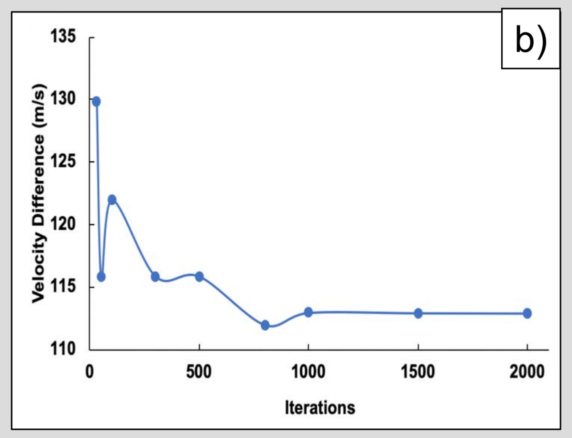
Conducted 7 iterations varying the mesh parameters of the selected mesh ⇨ Chose the final optimized mesh parameter

Results

Number of Iterations

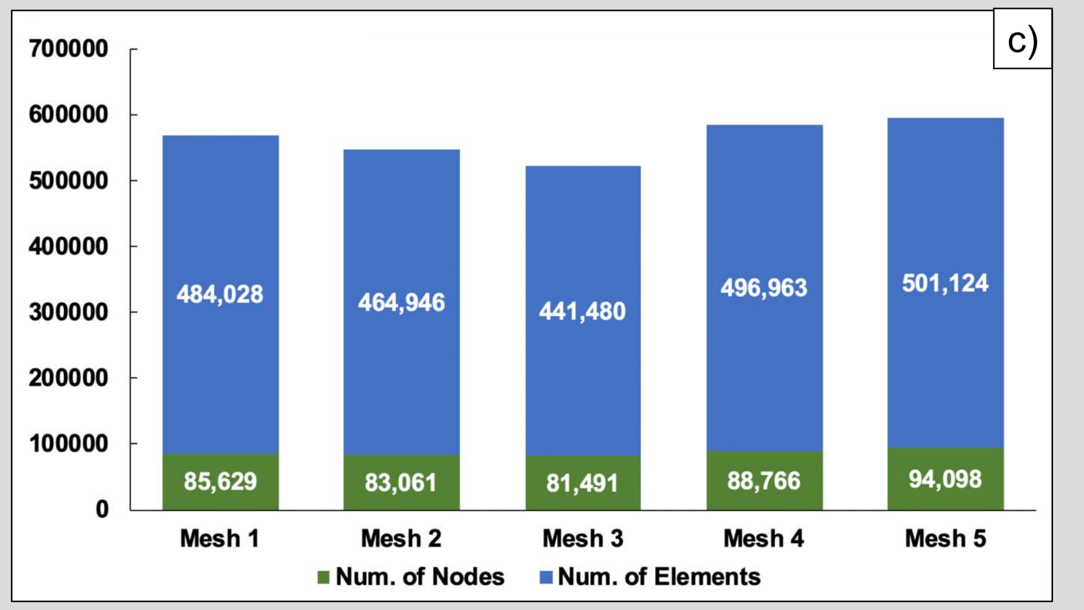
Curvature Normal Angle	20°
Number of Cells Across Gap	20





Pressure and velocity difference over the number of iterations used

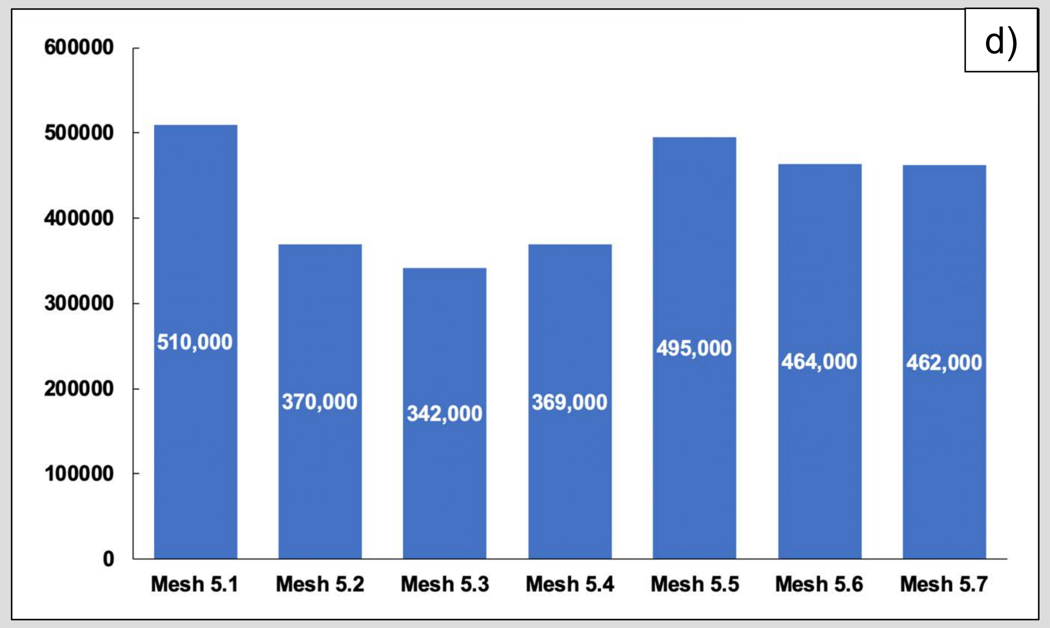
Mesh Parameters



Results Cont.

Mesh Parameters

Mesh Num.	Growth Rate	Defeature Size	Curvature Normal Angle	Num. Cells Across Gap	Face Element Size
Mesh 5.1	1.2	4.5405e-004 m	18.0°	3	3.1e-003 m
Mesh 5.2	1.3	4.5405e-004 m	18.0°	3	3.1e-003 m
Mesh 5.3	1.3	4.5000e-004 m	6.8°	15	3.1e-003 m
Mesh 5.4	1.3	4.5405e-004 m	18.0°	15	3.1e-003 m
Mesh 5.5	1.3	4.5405e-004 m	18.0°	16	3.1e-003 m
Mesh 5.6	1.3	4.5405e-004 m	18.0°	22	8.0e-003 m
Mesh 5.7	1.3	4.5405e-004 m	18.0°	22	3.1e-002 m



Conclusion

CFD Optimization Analysis

- Due to its generated steady-state convergence, 1,000 iterations was selected to be used for further studies.
- Mesh 5.7 was chosen due its reduced computational time in the form of minimized nodes and elements and also its consistent results – pressure difference for each plane and mesh combination were plotted.

Future work

- Utilize this study's optimization to conduct a CFD AMPS analysis per the works of Chowdhury et. al. [2, Patent Number: US 9,951,752]
- Improve the next generation of wind turbine by 1) maximizing power generation and 2) mitigating wind damage

References

[1] Gan Chowdhury, A., Moravej, M., Zisis, I., Irwin, P., Tremante, A., & Hajra, B. (2019). Mitigation of aerodynamic uplift loads using roof integrated wind turbine systems. *Frontiers in Built Environment*, *5*, 10.
[2] Chowdhury, A. G., & Tremante, A. (2018). *U.S. Patent No. 9,951,752*. Washington, DC: U.S. Patent and Trademark Office.
[3] Blessing, C., Chowdhury, A. G., Lin, J., & Huang, P. (2009). Full-scale validation of vortex suppression techniques for mitigation of roof uplift. *Engineering Structures*, *31*(12), 2936-2946.