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Aerodynamic mitigation of wind uplift loads on low-rise buildings

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ABSTRACT

This paper evaluates the effectiveness of aerodynamic roof mitigation devices in the reduction of roof suction produced by high-speed winds on low-rise buildings. Suction is the main cause of roof failure during various types of windstorms, such as hurricanes. Several roof mitigation devices are designed and tested by computational fluid dynamics (CFD) simulations. Modifications to eliminate the sharp corners that cause separation and lead to suction were carried out. In addition, different mitigation devices including barriers, circular edges, inclined edges and airfoil edges were investigated. The proposed mitigation devices are thought to be used on homes and other buildings with flat roofs to decrease wind-induced uplift and hence eliminate large-scale damage during hurricanes. Also, the paper focuses on exploring mitigation devices that not only can reduce loads on the roofs but also have minimum drag and lift forces.

1. INTRODUCTION

1.1 Background
In the world of engineering, a structure's capacity to resist loads is very important. One of the most destructive environmental loads placed on a structure is wind loading. Wind loads can range from strong winds causing little to no damage, to extreme winds from hurricanes, tornadoes, or heavy storms, causing massive destruction. When high velocity winds pass over the sharp corners of a bluff body it causes separation, as a result, a vortex forms on the roof causing an uplift effect that can detach roofs from low-rise buildings, like houses or office buildings. Peak suction is usually experienced at the corners of the windward edges. The destructive power of high velocity winds is seen often in areas prone to hurricanes.

1.2 Hurricanes impact
According to a report published by the NOAA's National Climatic Data Center (NCDC, 2013), in the year 2012, weather and climate disaster events caused losses exceeding $110 billion in damages and 377 deaths across the United States. This makes the year 2012 the second costliest on record, after the year 2005 which witnessed $160 billion losses due to hurricanes, including hurricane Katrina. The major driver of damage costs in 2012 was hurricane Sandy at approximately $65 billion. During the 1980-2005 period, the U.S. sustained over $500 billion in overall inflation adjusted damages/costs due to

extreme climate events (Lott and Ross, 2006). However, there is a significant increasing trend in billion-dollar disasters (Smith and Katz, 2013; Munich Re, 2012).

Wind-induced loads on low-rise buildings are a very significant design consideration. Extreme winds usually cause very high pressures on domestic homes and industrial/commercial buildings (Cochran and Levitan, 1994; Surry and Lin, 1995; Kawai and Nishimura, 1996; Banks and Muroney, 2001). The losses under hurricane winds basically include enclosure failure (doors and windows) and can be as large as whole roof failure. Once part of the roof failure is initiated, the rest of the building becomes very vulnerable and may cause a cascade failure of the whole building envelope (Cochran and English, 1997). The Institute for Business and Home Safety (https://www.disastersafety.org/) showed in both its Hurricane Ike and Charley reports that roofs had the highest failure rate out of all building components.

Even though advanced forecasts and warnings and more effective emergency responses can help reduce mortality (Willoughby et al. 2007), the economic impact of hurricanes is huge (Willoughby, 2012) and there is a need for a comprehensive research program to improve the resiliency and the sustainability of the built environment under extreme wind events. To improve the resiliency of our communities to natural disasters, new design techniques should be implemented, given the reality of limited resources. Promising solutions like aerodynamic mitigation and structural optimization are therefore needed.

(a) Slats **(b)** Flaps

Fig. 1 Similar to an airplane landing mechanism, aerodynamic features are inspired to reduce wind loads on buildings

1.3 Literature

The mitigation of roofs under wind loads will reduce hurricane related losses. Different roof mitigation strategies are suggested in the literature (Cochran and English, 1997; Banks et al., 2001; Bitsuamlak et al., 2013); however, novel practical and efficient solutions are needed. The shape of an airplane wing enables flight. The objective of an optimized roof shape with aerodynamic mitigation features is to avoid or reduce the chance of creating hurricane-induced loads that may damage the roof partially and cause it to become wind-borne debris. Wind loads on bluff bodies are governed by their shapes, among other factors. An aerodynamic mitigation approach should rely on shape modification as the way by which aerodynamic loads can be greatly reduced. Dynamics and passive control surfaces have been introduced to reduce wind loads on tall buildings, bridges, and roofs of low-rise buildings. Similar to the way in which the airplane is manipulated for takeoff and landing (Fig. 1), an aerodynamic roof edge can be designed to result in reduced total uplift loads on the roofs of low-rise buildings. In the literature, there are efforts to reduce the roofs' suctions by using barriers and grids.

Somewhat similar to this current study, many researchers have attempted to develop ways to prevent or reduce uplift. The majority of projects dealing with this subject use scaled building models with pressure taps in wind tunnels to simulate full-scale, real world data. Prasad et al. (2008) tested low-rise building models with flat, gabled and hip roof configurations in a boundary layer wind tunnel and found that the suction was significantly influenced by the roof configuration. There was a 91% reduction in peak suction by using a gabled roof as opposed to a flat one. Using the Wall of Wind, Chowdhury et al. (2007) tested six different roof geometries in which they observed the largest reduction of 74% in localized pressures, with the Flat Roof Aero Edge Guard. Mahmood et al. (2008) conducted experiments on 1:100 scaled Texas Tech University (TTU) test buildings in a wind tunnel under multiple flow conditions. They found that rounding the edges of the building greatly decreased suction. There was a maximum reduction of 80% in localized pressures. Pindado et al. (2006) found that cantilever parapets reduced suction because the air stream formed between the parapet and the building blows away the conical vortices. Banks et al. (2000) attempted to better understand the flow mechanism, which produces negative pressure coefficients by studying low-rise buildings in wind tunnels. It was found that the greatest suction occurred directly beneath the moving vortex core, but there was no relationship between vortex size and suction. Tieleman (2003) did a review of wind loads on low-rise structures from wind tunnel simulations experiments. He deduced that peak suction pressures on prisms are inherently associated with vortex generation under separated shear layers and peaks are observed under the corner vortices. Banks and Meroney (2001) studied rooftop surface pressures produced by conical vortices. They looked at the relationship between suction and upstream flow and found that the speed of the vortex spin is determined by the flow velocity component normal to the roof edge. Regardless of wind direction angle, the pressure above the vortex will be controlled by the speed of gusts passing over the roof corner.

Cochran and English (1997) used screens to suppress the conical roof vortices. Aerodynamic edges and devices also have been used (Banks et al., 2001; Blessing et al., 2009) as well as roof-edge parapets (Suaris and Irwin, 2010). However, a challenge with common architectural features (screens and aerodynamic edges) is the fact that the features may be expected to extreme wind loads in addition to debris which may result into a failure of the mitigation device. In any case, it is not only the mitigation of roof suctions at the corners, but also at the middle of large roofs, wind speed may create negative pressures (far from corners) that require a specific mitigation technique. The current study focuses on alternative features that not only can reduce the wind loads on the roof at its corners, but also can reduce the wind load at roof far from corners and most importantly minimize the loads on the mitigation feature itself. The effect of such mitigation devices will be quantified; comparisons among different techniques in terms of their simplicity and efficiency will govern the choice of the appropriate feature. While small scale-studies will be carried out in a wind tunnel, full-scale simulation will be carried out computationally to investigate the scale effects (Aly and Bitsuamlak, 2013).

1.4 Focus of the current paper

It is the focus of this paper to reduce wind-induced damage to buildings' roofs. In order to prevent uplift, flow separation must be reduced. This can be done by retrofitting the edges of the roof to be more aerodynamic like that of an airplane wing (streamline body). If the edges are engineered to be more streamlining, it will result in less separation and a reduction of uplift (see Fig. 1).

The purpose of the current study is to reduce adverse catastrophic hurricane effects on infrastructure by implementing innovative solutions to provide strategic guidance on the aerodynamic mitigation of structures. Aerodynamic mitigation of roofs of low-rise buildings will be carried out by examining proposed mitigation techniques. The current study focuses on mitigation features to reduce wind loads on roofs both at their corners and at the rest of the roof, in addition to creating minimal loads on the feature itself. Computational fluid dynamics (CFD) simulations were carried out to investigate the performance of proposed mitigation devices/techniques designed to eliminate the sharp corners that cause separation and lead to suction. TTU (Texas Tech University) building with a flat roof is used in the computational analysis, with and without the mitigation device.

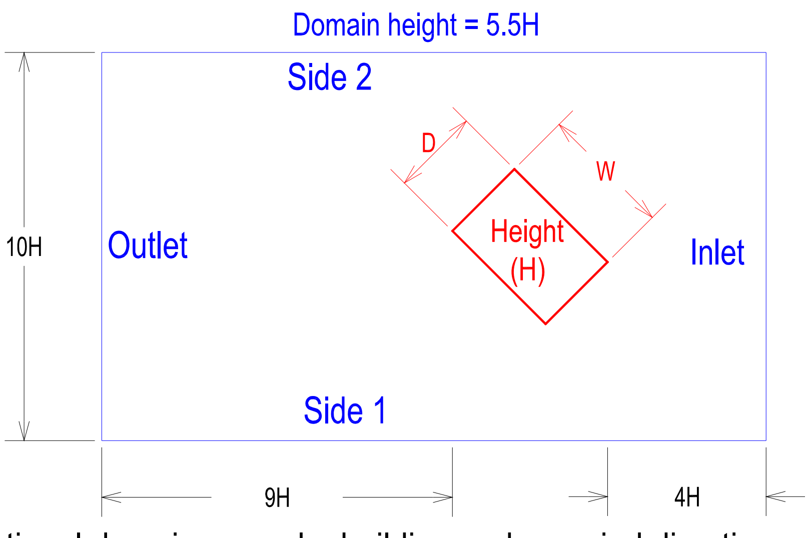


Fig. 2 Computational domain around a building under a wind direction angle of 45^{o}. The building height H was used as a parameter for setting the dimensions of the domain.

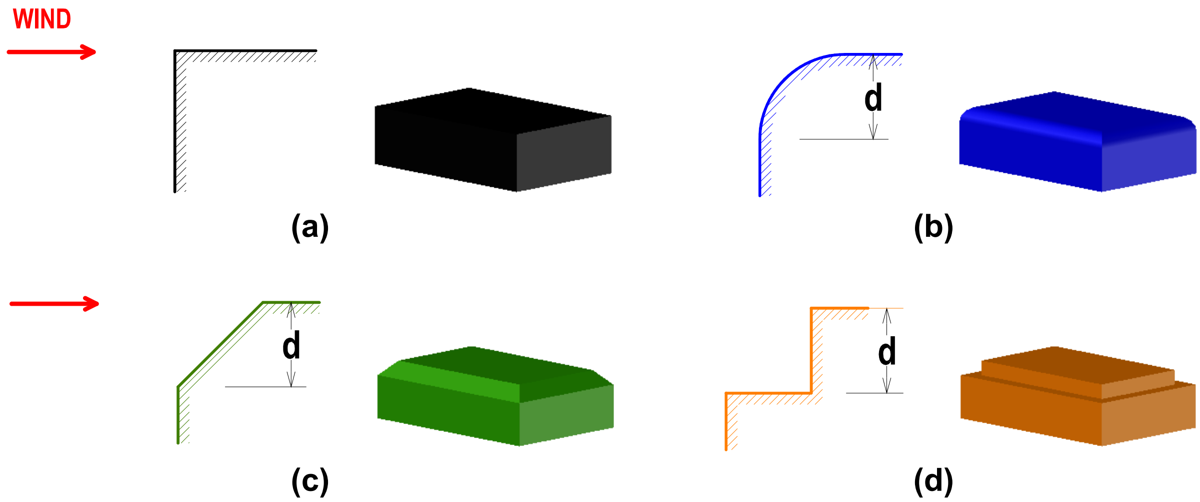


Fig. 3 Corner adjustment: (a) sharp; (b) rounded; (c) chamfered and (d) recessed corners. For each case, three different values for the dimension d were used to represent small, medium and large modifications to the corners. This created ten different testing models of flat roofs.

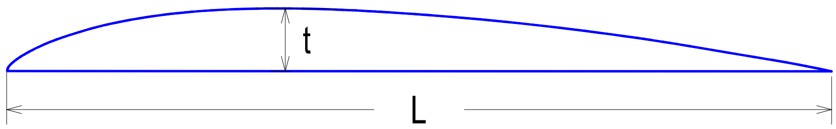


Fig. 4 USA 41 airfoil (half profile)

2. METHODOLOGY

Scaled models of TTU flat roof building was tested during this computational analysis. The flat roof building model had dimensions of W = 13.7 m (width), D = 9.1 m (depth), and H = 4m (height). The building was drawn inside a computational domain with dimensions length = 17H, width = 10H, and height = 5.5H, where H is the building's height (see Fig. 2). The models were drawn using AutoCAD Civil 3D for no mitigation devices, with corner modifications and with mitigation devices. Each computational test was run for wind directions of 45^{o}. The 1st mitigation technique is modifications to the roof corners by rounding; chamfering and recessing the edges (see Fig. 3). The second mitigation technique was carried out by implementing aerodynamic devices in the form of barriers, inclined barriers, curved edges, and airfoil edge. The airfoil shape indicated in Fig. 4 which represented the upper surface of the USA 41 airfoil was used. For design simplicity and since there is no significant airflow underneath the airfoil when attached to the roof, the lower surface of the devices was designed as a flat surface (eliminating the lower surface of the airfoil profile). Four both corner modifications and aerodynamic devices implementations, the size of the corner adjustment (dimension d as shown in Fig. 3) and the size of the device (dimension h as indicated in Fig. 5) where given three different values and three different simulations were run for every individual modifications. The dimensions d and h where set to represent small size (0.08H), medium size (0.16H), and large size (0.24H), where H is the building's height. This led to a total number of simulations of N = (1(bare roof)) + (3(sizes) x 3(corner modification cases)) + (3(sizes) x 6 (different aerodynamic devices)) = 28, as listed in Table 1 and Table 2. Each drawing was exported from AutoCAD into a .sat file to be imported into SolidWorks and then exported as a .igs file (to insure air tightness of the geometry) and then read in ICEM CFD where a high quality mesh was created.

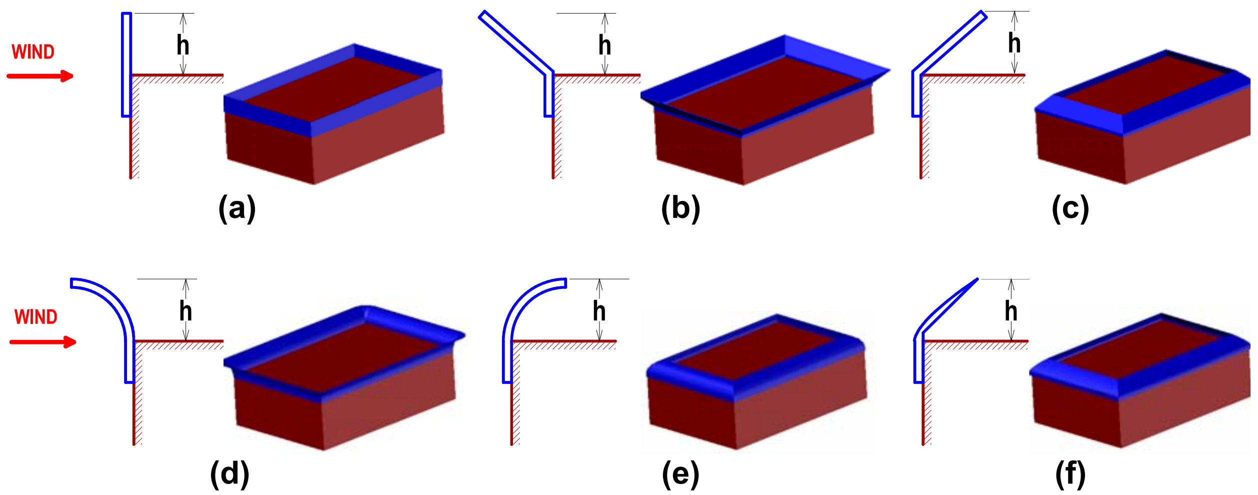


Fig. 5 Roof mitigation devices: (a) barrier; (b) barrier with an outer slope (slope-out); (c) barrier with an inner slope (slope-in); (d) circular device concaved out; (e) circular device concaved in; and (f) airfoil (half).

ICEM CFD was used through LSU's virtual lab. First the surfaces were defined as follows. The computational domain had inlet, outlet, roof, ground, side 1, and side 2 surfaces, while the building was one solid surface. The interior between the building and the computational domain was defined as a fluid. Next a mesh density was placed around the building in order to ensure that we better captured the flow details around the building without changing the entire mesh. Lastly the meshes from ICEM CFD were exported, and then imported into ANSYS FLUENT. FLUENT was used through LSU's High Performance Computing (HPC) facilities.

3. Results and Discussion

The results from the CFD simulations are listed in Table 1 and Table 2. Table 1 lists drag and force coefficients for flat roofs with different corners. The percentages of reduction/increase in the force coefficients are also listed in the table. Negative values designate reduction in the force coefficients while positive values indicate increase force coefficients w.r.t. a roof with sharp edges. It is shown that rounding the edges of the roof may lead to increased lift forces. Even if this approach can result into a significant reduction in the drag forces (16 %), it can cause significant increase in the lift forces (16 %), when a medium rounding to the edges was performed (rounding radius is about 16% of the roof's height). On the other hand, chamfered and recessed edges can lead to reduced drag and lift forces on the entire building. The lift force is reduced by about 10% when the edges where recessed with a size of about 24% of the roof's height. The results also show that unless the size of the corner modification is significant, there may be no significant reduction in the lift coefficient for a recessed corner. The chamfered corner can increase the lift coefficient for small chamfer size (8% of the roof's height). This said, it is recommended not to do any rounding to the corners of flat roofs on low-rise buildings. Chamfered edges may help reduce the lift forces and can significantly reduce drag forces on the entire building. Recessed corners are shown to offer the best reduction in the total roof uplift forces.

Table 1 effects of corner modification (see Fig. 3) on the aerodynamic drag and lift force coefficients on a building with flat roof under wind direction angle of 45^o.

Corner	Size	Drag and force coefficients		Recommendation
		C_d	C_l	
Sharp	__	1.06	1.33	____
	small	0.93 (-12.4%)	1.37 (+2.6%)	No
Chamfer	medium	0.88 (-16.9%)	1.31 (-1.3%)	No
	large	0.85 (-20.0%)	1.24 (-6.6%)	Yes
	small	0.93 (-12.3%)	1.51 (+13.3%)	No
Rounded	medium	0.89 (-15.9%)	1.54 (+16.1%)	No
	large	1.06 (+0.3%)	1.32 (-0.6%)	No
	small	0.97 (-8.9%)	1.31 (-1.4%)	No
Recessed	medium	0.93 (-12.4%)	1.27 (-4.8%)	Yes
	large	0.89 (-16.1%)	1.19 (-10.2%)	Yes

Table 2 lists the force coefficients on the entire building and the mitigation devices proposed in the current studies for 18 different mitigation cases, in addition to the bare roof case (no mitigation). Because the mitigation device will be attached to previously erected structures, it is important to evaluate the load placed on the devices. The tables lists the values of the drag and lift force coefficients for each mitigation device. The ideal device would have the minimal drag and lift coefficient which would result in a smaller chance of the device be damaged or destroyed. Five different mitigation devices termed barrier, slope-out, slope-in, circular-out, circular-in, and airfoil were investigated (see also Fig. 5). Each mitigation device was considered at three different sizes: small (8% of building's height), medium (16% of roof's height) and large (24% of roof's height).
Table **3** lists percentages of reduction/increase in lift and drag force coefficients. The results show that slope-out and circular-out devices are not performing significantly compared with the other mitigation devices. Both devices have large drag forces which can additional loads to the original building. In addition the circular-out device can lead to increased uplift forces at both medium and large sizes. As a general rule, it can be stated that larger the mitigation device, larger the drag forces produced on the devices which leads to increased total drag forces that the whole structures should resist. At a

certain size, the barrier will bring the heights drag forces, compared to slope-in, circular-in and the airfoil. The three devices can bring significant reduction in the total uplift forces produced on the whole structure ranging from 22% to 28% at small sizes. The corresponding reduction in the roof uplift forces is ranging from 29% to 36%. Changing the shape of the device from a slope-in to circular-in or airfoil brings additional reduction in the roof's uplift forces with the cost of increased drag forces on the mitigation device. Compared to the slope-in and the circular-in, the airfoil can bring the maximum reduction in the total uplift forces produced on both the building and the devices. The slope in device is still recommended for its simpler geometry (for manufacturing purposes).

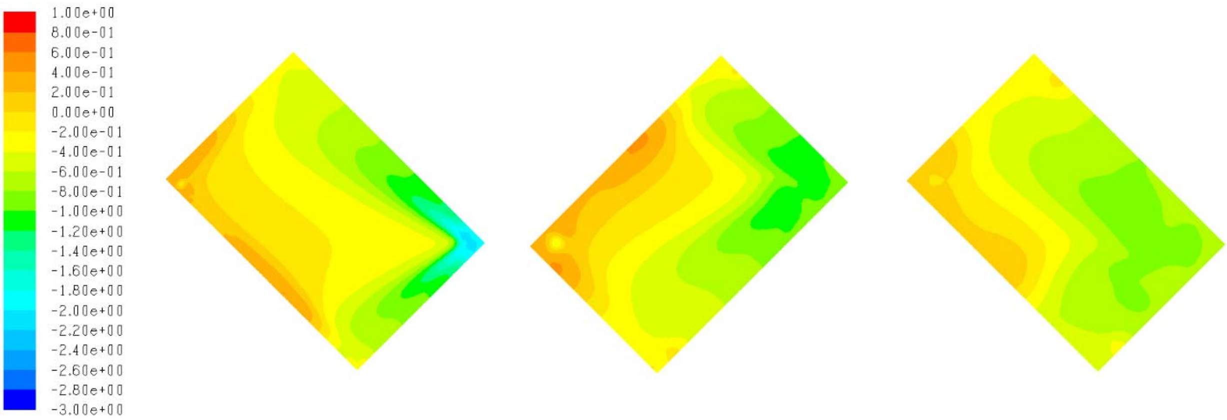
Table 2 Force coefficients on the building and the mitigation devices proposed in the current studies for 18 different mitigation cases, in addition to the bare roof case.

Config.	Size	Building's Force Coef.		Device's Force Coef.		Total Force Coef.	
		C_d	C_l	C_d	C_l	C_d	C_l
Bare Roof	__	1.06	1.33	__	__	1.06	1.33
Barrier	small	1.14	1.03	0.27	0.05	1.41	1.07
	medium	1.18	1.03	0.48	0.04	1.66	1.07
	large	1.23	1.18	0.66	0.04	1.88	1.23
Slope-out	small	1.12	0.97	0.28	0.20	1.40	1.17
	medium	1.20	0.82	0.54	0.36	1.74	1.18
	large	1.29	0.75	0.81	0.51	2.10	1.26
Slope-in	small	1.06	0.94	0.13	0.10	1.19	1.04
	medium	1.12	0.94	0.28	0.09	1.40	1.03
	large	1.14	1.17	0.35	0.02	1.49	1.19
Circular-out	small	1.10	1.02	0.28	0.26	1.38	1.28
	medium	1.18	0.84	0.49	0.52	1.67	1.36
	large	1.24	0.72	0.71	0.77	1.95	1.50
Circular-in	small	1.08	0.85	0.14	0.16	1.21	1.01
	medium	1.11	0.76	0.25	0.29	1.36	1.05
	large	1.12	0.92	0.33	0.35	1.45	1.26
Airfoil	small	1.09	0.87	0.15	0.09	1.24	0.96
	medium	1.12	0.86	0.27	0.14	1.39	1.01
	large	1.14	1.06	0.36	0.13	1.50	1.20

Fig. 6 shows that mean pressure coefficient distribution on a roof with a slope-in mitigation device is dependent on the size of the device. Although the smaller size brought the best reduction the total uplift forces, a localized pressure at the leading edge of the building shows some significant suction. This localized negative pressure can be eliminated be increasing the size of the mitigation device. The mitigation devices play an important role in reducing suctions especially at the leading edges of the building (see Fig. 7).

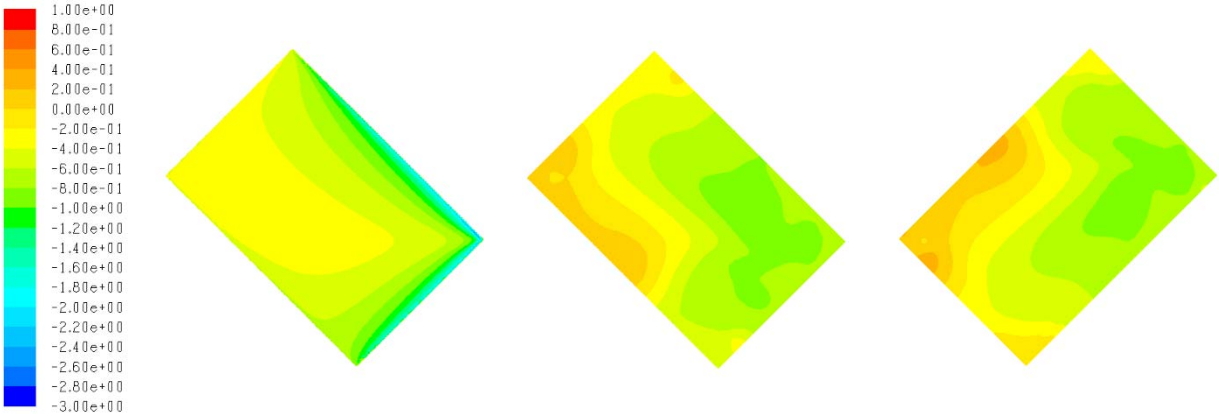
Table 3 Percentages of reduction/increase in the aerodynamic force coefficients.

		Building's Force Coef.		Total Force Coef.	
Device	**Size**	C_d	C_l	C_d	C_l
	small	7.5	-22.9	32.8	-19.4
Barrier	medium	11.4	-22.7	57.0	-19.3
	large	15.8	-11.1	77.8	-7.9
	small	5.8	-27.1	32.5	-12.0
Slope-out	medium	13.6	-38.1	64.4	-11.0
	large	21.6	-43.7	97.7	-5.0
	small	-0.3	-29.2	12.3	-22.0
Slope-in	medium	5.6	-29.0	31.8	-22.2
	large	7.5	-12.3	40.7	-10.5
	small	4.2	-23.4	30.3	-3.9
Circular-out	medium	11.1	-36.5	57.7	2.2
	large	16.9	-45.7	84.3	12.5
	small	1.6	-35.9	14.5	-24.1
Circular-in	medium	4.6	-42.8	28.5	-21.3
	large	5.7	-31.1	36.5	-5.1
	small	3.1	-34.8	16.8	-27.9
Airfoil	medium	5.8	-35.0	31.5	-24.1
	large	7.7	-20.2	41.2	-10.0



(a) (b) (c)

Fig. 6 Mean pressure distribution on a roof with a slope-in mitigation device: (a) small; (b) medium; and (c) large.



(a) (b) (c)

Fig. 7 Effect of the mitigation devoice on the mean pressure distribution on a flat roof: (a) bare roof; (b) slope-in; and (c) airfoil.

4. CONCLUSIONS

The study presented in the current paper attempts at evaluating the performance of aerodynamic roof mitigation techniques/devices in the reduction of roof suctions produced by high-speed winds on low-rise buildings. Several roof mitigation techniques/devices were proposed and tested by computational fluid dynamics (CFD) simulations. Corner modifications to eliminate the sharp edges that cause separation and lead to suction were carried out. In addition, different mitigation devices including barriers, circular edges, inclined edges and airfoil edges were investigated. The paper focuses on exploring mitigation devices that not only can reduce loads on the roofs, but also have minimum drag and lift forces. The contributions of the current paper can be summarized as follows:

- For the purpose of sharp corner modifications for flat roofs to reduce aerodynamic loads, it is shown that rounding the corners does not bring significant reductions in the total uplift forces on a building. This technique should be avoided for the roofs of low-rise buildings. Furthermore, roofs with rounded edges can increase the lift forces on the whole building under a wind direction angle of 45^o.
- Only flat roofs with significant chamfers can bring slight reductions in the total uplift forces. For the case of a 24% of roof's height chamfer, the reduction is about 6%. This said, it is not recommended to produce chamfers on the roofs of low-rise buildings as small chamfers do not bring reductions to the uplift loads. However, the reduction in the drag forces can be significant (12-20%).
- Roofs with modified corners to produce recesses can bring reductions in the uplift load of about 10% for a recess size of about 24% of the roof's height.
- The addition of aerodynamic features to the roofs of low-rise buildings with flat roofs can bring significant reduction to the uplift forces. Depending on the shape of the mitigation device, reduction in the total uplift forces on buildings can be very significant with minimal drag forces on the device.
- Aerodynamic features including barriers, slope-in, circular-in and airfoils can bring significant uplift reductions to the whole structure (roof + device) as 20%,

22%, 24%, and 28% respectively. The corresponding increases in the drag forces on the whole structure (building + device) are 32.8, 12.3, 14.5 and 16.8%, respectively.

- The simple shape of slope-in mitigation feature makes it attractive for uplift reduction on flat roofs with minimal drag forces on the features.
- The airfoil feature is shown to produce the minimum uplift loads on the whole structure (roof + feature).

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REFERENCES

Aly, A.M. and Bitsuamlak, G. (2013), "Aerodynamics of ground-mounted solar panels: test model scale effects," *Journal of Wind Engineering and Industrial Aerodynamics*, **123**, 250-260.
Aly, A.M. and Bitsuamlak, G. (2013), "Aerodynamics of ground-mounted solar panels: test model scale effects," Journal of Wind Engineering and Industrial Aerodynamics, 123, 250-260.
Banks, D., and Meroney, R. N. (2001). "A model of roof-top surface pressures produced by conical vortices: Model development." J. Wind and Structures., 4(3), 227-246.

Banks, D., and Meroney, R. N., Sarkar, P.P., Zhao, Z., and Wu, F. (2000). "Flow visualization of conical vortices on flat roofs with simultaneous surface pressure measurements." Journal of Wind Eng. And Industrial Aerodynamics, 84, 65-85.

Banks, D., and Meroney, R.N. (2001), "A model of roof-top surface pressures produced by conical vortices: Model development," Wind and Structures, 4(3), 227-246.

Banks, D., Sarkar, P., Wu, F. and Meroney, R.N. (2001), "A device to mitigate vortex induced rooftop suction," Proceedings of the 1st Americas Conference on Wind Engineering, Clemson University, Clemson, South Carolina, June 4-6.

Bitsuamlak, G., Warsido, W., Ledesma, E. and Chowdhury, A. (2013), "Aerodynamic mitigation of roof and wall corner suctions using simple architectural elements", Journal of Engineering Mechanics, 139, 396–408.

Blessing, C., Chowdhury, A. G., Lin, J. and Huang, P. (2009), "Full-scale validation of vortex suppression techniques for mitigation of roof uplift", Engineering Structures, 31(12), 2936–2946.

Chowdhury, A.G. (2007). "Hurricane Loss Reduction For Housing in Florida: Mitigation of Roof Uplift Through Vortex Suppression Techniques." International Hurricane Research Center, FL.

Cochran, L., Levitan, M. (1994), "Lessons from hurricane Andrew," Architectural Science Review, 37(3), 115-121.

Cochran, L.S., English, E.C. (1997), "Reduction of roof wind loads by architectural features," Architectural Science Review, 40, 79–87.

Kawai, H., Nishimura, G. (1996), "Characteristics of fluctuating suction and conical vortices on a flat roof in oblique flow," Journal of Wind Engineering and Industrial Aerodynamics, 60, 211–225.

Lott, N., Ross, T. (2006), "Tracking and evaluating U.S. billion dollar weather disasters, 1980– 2005," The 86th annual meeting of the American Meteorological Society, Atlanta, Georgia, January 29 – February 2.

Munich Re, (2012), “Severe weather in North America, perils, risks, insurance,” Knowledge Series, Natural Hazards, Munich Re Group, Munich.
NCDC, National Climatic Data Center, (2012), “Billion-Dollar Weather/Climate Events,” Available online: http://www.ncdc.noaa.gov/billions.
Pindado, S., Meseguer, J., Franchini, S., and Barrero, A. (2006). “On the reduction of the wind–load on building by using cantilever parapets.” Institute IDR/UPM, Madrid, Spain.
Prasad, D., Uliate, T., and Ahmed, M.R. (2008). “Wind Loads on Low-Rise Building Models with Different Roof Configurations.” University of the South Pacific, Suva, Fiji.
Smith, A.B., Katz, R.W. (2013), “US billion-dollar weather and climate disasters: data sources, trends, accuracy and biases,” Nat Hazards, 67, 387-410. DOI 10.1007/s11069-013-0566-5
Suaris, W., Irwin, P. (2010), “Effect of roof-edge parapets on mitigating extreme roof suctions,” Journal of Wind Engineering and Industrial Aerodynamics, 98, 483–491.
Surry, D., and Lin, J.X. (1995), “The effect of surroundings and corner geometric modifications on roof pressure on low-rise buildings,” Journal of Wind Engineering and Industrial Aerodynamics, 58, 113–138.
Tieleman, H.W. (2003). “Wind tunnel simulation of wind loading on low-rise structures: a review.” Journal of Wind Eng. and Industrial Aerodynamics, 91, 1627-1649.
Willoughby, H. E., Rappaport, E. N., Marks, F. D. (2007), “Hurricane forecasting: The state of the art,” Natural Hazards Review, 8(3), 45–49.
Willoughby, H.E., (2012), “Distributions and trends of death and destruction from hurricanes in the United States, 1900–2008,” Natural Hazards Review, 13, 57–64.