# OBSERVATIONS OF THE WIND DAMAGE IN THE ANGUS (ONTARIO) TORNADO OF JUNE 17, 2014

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**Abstract**

A tornado occurred between 5:00 and 6:00 PM on June 17, 2014 in Angus, Ontario. The authors conducted a damage investigation on the morning following the storm. The damage indicators support the classification that the tornado was an EF-2 tornado, including the observation of several complete roof failures of recently-constructed, wood-frame houses. Most of the damage was contained along two streets, with the tornado appearing to have gone down the backyards between the two. In total, 101 houses were observed to have sustained some level of damage. The evidence suggests that the quality of construction likely affected the performance of failed roofs. An overturned truck provided the opportunity to correlate this failure with adjacent, repetitive failures of roof sheathing, shingles and garage doors.

## 1 INTRODUCTION

Wind speeds in tornadoes are rarely measured; rather, they are assessed indirectly by examining the damage following the storm and estimating the wind speeds that could have caused this damage. The original basis for this was the Fujita Scale (Fujita, 1971), which was modified into the Enhanced-Fujita Scale (EF-Scale) by Texas Tech University (WSEC, 2006). Canada adopted a slightly modified EF-Scale in 2013 (Sill et al., 2014). One of the challenges with the EF-Scale is that it was developed based on expert opinion (Mehta, 2013), rather than engineering calculations, primarily because of the limited availability of relevant data or analyses. Researchers at the University of Western Ontario have been conducting research for the past decade to help fill this gap, with studies in particular of the performance of wood-frame houses (e.g., Morrison et al., 2012; Henderson et al., 2013; Stedman, 2014) at the "3 Little Pigs" Project (Kopp et al., 2012) and in the wind tunnel studies of houses (e.g., Gavanski et al. 2013, 2014) and vehicles (e.g., Stedman, 2012). In addition, these researchers have developed tools for assessing wind speeds from damage in extreme wind events (Kopp et al., 2011) and assessed wind speeds in tornadoes from other events in Canada (Morrison et al., 2014). The tornado in Angus, Ontario, on June 17, 2014 provides another opportunity to correlate damage observations with lab-based research results in order to improve assessments of wind speeds in tornadoes.

On June 17, 2014, between 5:00-6:00 PM, a severe thunderstorm hit Angus, Ontario, which included a tornado. On the morning following this event, the authors conducted a damage survey of the area. As will be seen, the observed damage supports the classification of the tornado as EF-2. The storm occurred in an area with many residential, wood-frame houses. Many of the houses that were damaged had been constructed fairly recently, and were typically less than 3 years old (based on dates of manufacture on air conditioning units and the presence or absence of houses on the Google earth map). The damage varied from shingle and siding failures to complete roof and wall failures, with a large moving van also overturned. The objective of this paper is to present the statistics of the damage observations, with an emphasis on the correlation between repetitive failures of shingles, roof sheathing and garage doors adjacent to the van failure. Wind tunnel test results for the overturning of such a vehicle are presented for comparison.

## 2 DAMAGE OBSERVATIONS

### 2.1 Overview

Figure 1 shows the survey area within Angus and the locations of houses with damage. This figure illustrates that much of the damage was located on two streets, Stonemount Cres. and Banting Cres., and that away from these two streets there was only scattered damage. Additionally, the further away the houses were from the centre of the path of the storm, the less severe the damage was. In total, 101 houses were identified with visible damage from the storm. Figure 1 also shows that there were 11 houses that lost their roofs, and that these were located in close proximity to each other on Stonemount Cres. In addition, many (8) of the roof sheathing failures occurred close to these complete roof failures on Stonemount Cres., with only 3 sheathing failures observed on Banting Cres. The difference in the damage level on these two streets is dramatic, as can be seen in Figure 2. The centre of the tornado track appeared to be between these two streets, perhaps through the backyards between the houses. In fact, it was observed that most of the debris was contained to these two streets.

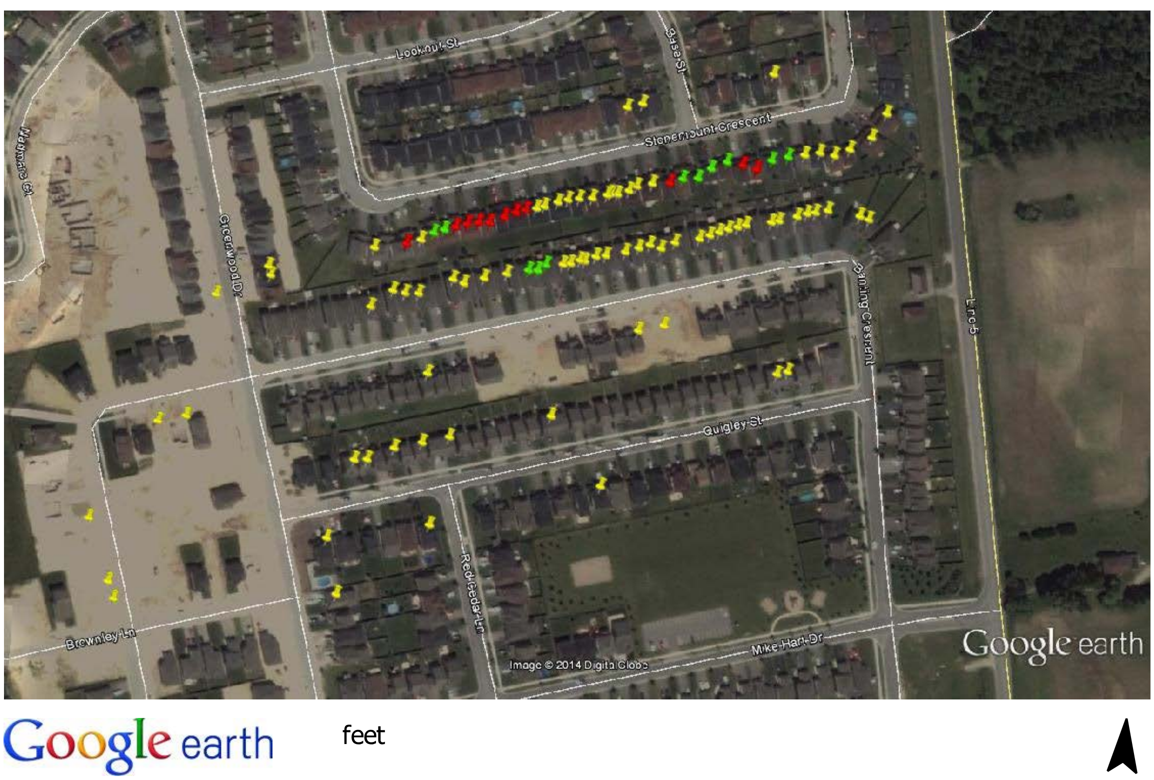


*Figure 1. Summary of all damage observations in Angus, ON, from survey of June 18, 2014. Red symbols indicate global roof failure, green symbols roof sheathing failures (while the roof structure remained in place), while yellow symbols indicate all other damage. Note that construction was still occurring in this neighbourhood, so not all houses appear in the Google earth map.*

Judging by the debris found between Stonemount Cres. and Banting Cres. the tornado tracked from west to east (left-to-right on Figure 1). The width of the storm was estimated to be between 25-30 m. Surrounding the surveyed area, tree damage was found both to the west and to the east of the highly damaged area, and tended to be in line with the damage through the backyards. The tornado damage originated in the west end of Angus and extended for 20 km east of Angus, ending near Innisfil, south of Barrie (as determined by Environment Canada). The path that exhibited EF-2-level damage extended for about 300 m. Examining the damage patterns and movement of debris, it appeared as though the tornado core was quite narrow, but with a vortex translation speed that was high compared to its rotational speed.

*Figure 2. Photograph of the backyards of the houses on Stonemount Cres. (left side of photograph) and Banting Cres. (right side).*

As described earlier, there were a variety of different levels of damage found with 101 houses identified with visible damage (from the street). Table 1 summarizes the observed damage found indicating the damaged components. In the table, roof failure indicates the structural failure of the roof, which was usually failure of the toe-nailed, roof-to-wall connections. When this type of failure occurs, the roof usually flies off of the walls. However, toe-nail failures do not always lead to flight of the roof, as shown in Kopp et al. (2012). Such failures can only be identified by examining connections within the house, which was not done in the current study. Roof sheathing failures are not considered structural, although failure of many panels can lead to significant structural issues. Sheathing is also critical to keeping rain out and reducing the overall financial loss (Sparks et al., 1994). Debris impacts are often related to structural failures (Morrison et al., 2014) by elevating the internal pressures (Kopp et al., 2008). Here, debris failures indicate only the number of houses where the damage (of any kind) appears to be directly the cause of failure.

*Table 1. Summary of Damage Observations in Angus, ON.*

| Damage | Quantity |
|---|---|
| **Roof Structural Failure** | 11 |
| **Fascia/Soffits/Eaves** | 36 |
| **Siding** | 28 |
| **Shingles** | 48 |
| **Roof Sheathing** | 11 |
| **Walls** | 9 |
| **Porch Columns** | 4 |
| **Debris Impact** | 38 |
| **Garage Doors** | 9 |
| **Broken windows** | 23 |
| **Bricks** | 4 |
| **U-Haul Truck Overturned** | 1 |
| **Total Houses** | 101 |

### 2.2 Structural Roof Failures

The most severe damage was roof structure failure. Houses that had experience roof structural failure are usually condemned and demolished. Most of these also lose most of their contents due to rain (and wind) damage. Ten of the 11 houses with complete roof failure had the roof becoming detached and blowing off of the walls. On the other house with roof failure, the roof was displaced, but did not blow off. The blown-off roofs travelled eastward, along with other debris, and in some cases impacted adjacent houses. Figure 3 shows one of the roofs, which travelled from Stonemount Cres and impacted two houses on Banting Cres. The source house, with the roof failure, was not unidentifiable. Such roof trusses often penetrated the roof and wall sheathing.

*Figure 3. An example of damage caused by debris impacts. This roof had collided with the side of the two houses and as seen in the picture. Many roof trusses are seen in the pile; this roof had blown from a house on Stonemount Cres., across the backyards, ending by impacting these houses on Banting Cres.*

*Figure 4. Roof truss from a house on Stonemount Cres. This roof truss had only 1 toe-nail in the connection, rather than the code-required 3.*

As seen in Figures 1 and 5, many of the houses that had lost their roofs were adjacent to each other. There are three main factors that could be the cause of this. Firstly, closely spaced houses with nearly continuous ridge-lines can increase the wind loads. In Angus, it is not clear if this played any role since these houses had hip roofs such that the ridge-lines were discontinuous. Secondly, the authors examined the connections for all of the failed roof trusses that could be identified on the ground and from high-resolution photographs of those remaining on the roof which could be seen from the yard. Practically all of toe-nailed roof-to-wall connections (RTWC) were found to be below code requirements, with cases of 0, 1, and 2 nails in the connections, rather than the code-required 3. However, only a relatively small number of RTWC could be definitively identified, so any conclusions based solely on this evidence is tentative. (There is additional evidence of poor construction quality associated with wall failures, which is discussed further below.) Figure 4 shows an example of one roof truss, there was evidence of only a single nail being present. Thus, improper toe-nailed RTWC undoubtedly played a role in (at least some of) the roof failures. Finally, in the Vaughan, ON, tornadoes in August of 2009 (see Morrison et al., 2014), internal pressures clearly contributed to roof failures. In contrast, the Angus tornado does not appear to have similar internal-pressure-related failures, although it is possible that these played some role, because of the direction of flight of the roofs relative to the locations of openings (which were on the same side of the structures). All three of these points could use further examination to determine their relative contributions to the failures.

*Figure 5. House with observed roof and wall failure. The second story of this house has been blown open. The connections have come apart and the wall has been fallen nearby.*

### 2.3 Roof Sheathing

Of the remaining damaged houses (i.e., not counting those with structural roof failure), 11 had at least one roof sheathing panel failure. Variable numbers of panels failed, with about a third of the houses of losing only one panel and another third of them losing multiple panels. Houses with similar numbers of panel failures were grouped closely together. Many of the houses with missing panels were located near houses that had lost their roof, indicating that the tornado wind speeds may have been more intense in these locations. Examining the sheathing panels found in the debris, the nail sizes exceeded the code minimum values of 51 mm (6d) in length, with mostly 63 mm (8d) nails found. The failed-panel locations on the roof varied from house to house; however, there were some similarities between adjacent houses, with some repeated patterns. However, these patterns were more pronounced with the shingle loss than the sheathing loss (due to greater numbers). When examining sheathing based on the orientation of the roof, with many failures closer to the bottom edge of the roof, i.e., at the eaves, while other roofs had sheathing failures at about the mid-roof height near the hip-lines. Many of the missing panels were grouped together in either horizontal rows or as a large opening with the missing panels not being in the same row but just grouped together.

### 2.4 Debris-Impact Damage

In total, there were 38 houses that were observed to have experienced debris impact damage. This category varied with some houses taking heavy damage from many pieces of debris, while others had less damage, which could be observed as broken windows or pieces of wood impaling the vinyl siding. This damage could be categorized as roof impacts, broken windows and siding and impacted garage doors. The roof impacts were considered to be the worst debris damage. Roof impacts were the damage caused by a house losing its roof and the subsequent movements of the roof as it was carried by the storm. In total, there were 8 houses that clearly experienced debris impact from large portions of roofs. In any case, it was clear that most of the roof impacts were caused by upwind houses losing their roofs with the roof components impacting neighbouring houses. While it is difficult to assess, debris impacts appear to have been caused by houses losing their roofs 20 – 50 m upwind (noting that the roofs did not always fly off as can be seen in Figure 5.

The impact to siding and broken windows was common among the houses along the storm track. In total, 24 houses received window damage and more with siding damage. Almost all of these houses were located along the highly-damaged area. The siding damage consisted of numerous cuts, tears and dents, with roof structural members often penetrating the walls. There were multiple screen door failures as well. Additionally, there were more structural wall failures due to debris, one example being shown in Figure 2. There were multiple garage door failures, which could have been from high wind pressures or from debris impacts. In total, there were 9 garage doors on Banting Cres. blown off their hinges or cracked.

### 2.5 Wall Failures

As discussed above, there were two main causes of structural wall damage: wind-induced pressures and impact from wind-borne debris. There were 6 houses believed to have had pressure-driven wall failures. Many of these failures were unique. Half of these houses had also lost their roof, which compromised the wall as a result – Figure 5 shows one of these. Figure 6 shows a house with the roof still attached, which has clearly experienced wall damage. Here the siding had been blown off revealing the failure in the inter-storey, wall-to-floor connections

### 2.6 Porch Column Failures

Several houses had porches supported by columns. Currently, the NBCC and OBC have no requirements pertaining to the upward-acting vertical load paths on columns; thus, it is acceptable for the roof to be loosely-laid above the column with the downward-acting vertical load path maintained by gravity loads. Thus, only gravity loads from the roof are assumed to be acting on porches and porch columns and the column is either fastened by an arbitrary number of nails or the roof is loosely laid on the column. During the Angus tornado, several columns failed, as indicated in Table 1. If the primary wind directions had been slightly different, it is possible that there would have been many more failures, and potentially total roof failures because of this.

*Figure 6. Wall failure due to missing inter-storey connections.*

## 3 WIND TUNNEL TEST RESULTS FOR OVERTURNED TRUCKS

One of the interesting failures in Angus was a U-Haul truck which was overturned by the wind, as shown in Figure 7. Of particular interest are the repetitive failures of shingles, sheathing and garage doors in the background. In the Enhanced-Fujita Scale (EF-Scale), damage to one and two-family wood-frame houses is categorized into 10 Degrees-of-Damage (DOD). For DOD-4, the damage is indicated as “uplift of roof deck and loss of significant roof covering material (20% or more); collapse of chimney; garage doors collapse inward; failure of porch or carport.” This is precisely what has been observed on Banting Cres. The EF-Scale suggests that this level of damage is associated with wind speeds in the range from 130 – 187 km/hr, and an expected value of 156 km/hr. This is in the EF-1 range of wind speeds. Our interest here is to assess by studying blow-over speeds for a U-Haul Truck in a wind tunnel. Such a scenario was examined by Stedman (2012), where details can be found.


*Figure 7. Overturned U-Haul truck in the foreground with repetitive shingle, roof sheathing and garage door failures on houses on Banting Cres. in the background.*

*Table 2. Degree-of-damage (DOD) descriptions and expected wind speeds in the EF-Scale used by Environment Canada for one- and two-family residences (100 – 500 m$^2$).*

| Degree-of-Damage | Damage Description | Expected value (km/hr) | Lower bound (km/hr) | Upper bound (km/hr) |
|---|---|---|---|---|
| 1 | Threshold of visible damage | 105 | 85 | 129 |
| 2 | Loss of roof covering material (less than 20%), gutters and/or awning; loss of vinyl or metal siding | 127 | 101 | 156 |
| 3 | Broken glass in doors and windows | 154 | 127 | 183 |
| 4 | Uplift of roof deck and loss of significant roof covering material (20% or more); collapse of chimney; garage doors collapse inward; failure of porch or carport | 156 | 130 | 187 |
| 5 | Entire house shifts off foundation | 195 | 166 | 227 |
| 6 | Large sections of roof structure removed; most walls remain standing | 196 | 167 | 229 |
| 7 | Exterior walls collapsed | 212 | 182 | 246 |
| 8 | Most walls collapsed, except small interior rooms | 245 | 204 | 286 |
| 9 | All walls collapsed | 274 | 229 | 319 |
| 10 | Destruction of engineered and/or well-constructed residence; slab swept clean | 322 | 266 | 354 |

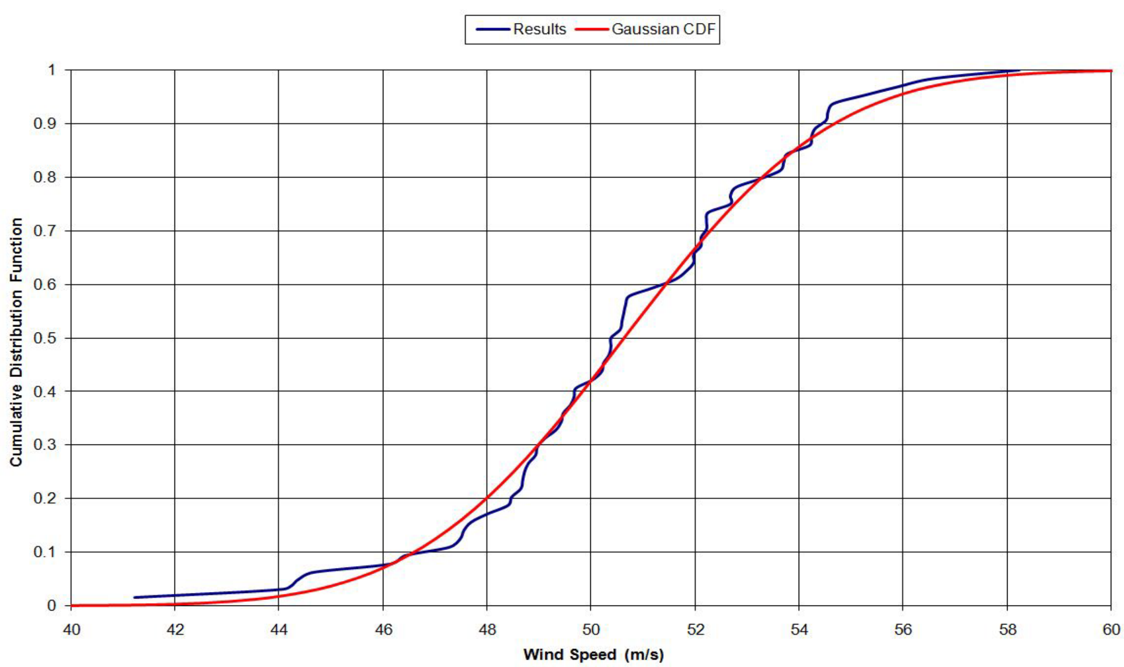


*Figure 8. Cumulative Distribution Function of failure gust wind speeds of a 27 ft U-Haul truck measured in the wind tunnel.*

Figure 8 shows results from Stedman (2012), which indicates a range of possible overturning speeds for an empty U-Haul Truck of 45 – 56 m/s (162 – 202 km/hr) for the range from the $5^{th}$ – $95^{th}$ percentile. This range considers all wind directions. Thus, there is substantial overlap in the range and the EF-Scale appears to give reasonable values based on this single study. Thus, the overturned truck is consistent with, and highly-correlated to EF-1 damage.

## 4 CONCLUSIONS

The damage observed in the storm was consistent with the EF-2 category, based on complete roof failures of wood-frame houses. The post-storm field survey indicated that much of the structural roof and wall damage was associated with poor construction quality caused by missing toe-nails in the roof-to-wall connections and nails in the inter-story wall-to-floor connections. However, all of the roof failures could not be definitively associated with this so the EF-2 category still appears to be a reasonable assessment at this stage. An overturned U-Haul truck was also observed in the field survey to be well correlated with repetitive shingle, roof sheathing, and garage door failures. A wind tunnel study of overturning trucks indicates the range of speeds for DOD-4 for one and two-family, wood-frame houses appears to be reasonable, and so the speeds associated with overturned truck correspond well to EF-1 wind speeds and damage.

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## 6 REFERENCES

Fujita, T.T., 1971, Proposed characterization of tornados and hurricanes by area and intensity. Satellite and Mesometeorology Research project Report 91, University of Chicago, Chicago, IL, USA.

Gavanski, E., Kordi, B., Kopp, G.A. & Vickery, P.J., 2013, Wind loads on roof sheathing of houses, *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 114, pp. 106-121.

Henderson, D.J., Morrison, M.J. & Kopp, G.A., 2013, Response of toe-nailed, roof-to-wall connections to extreme wind loads in a full-scale, timber-framed, hip roof, *Engineering Structures*, vol. 56, pp. 1474-1483.

Kopp, G.A., Oh, J.-H. & Inculet, D.R., 2008, Wind-induced internal pressures in houses, *ASCE Journal of Structural Engineering*, vol. 134, pp. 1129-1138.

Kopp, G.A., Morrison, M.J., Kordi, B. & Miller, C., 2011, A Method to Assess Peak Storm Wind Speeds Using Detailed Damage Surveys, *Engineering Structures*, vol. 33, pp. 90-98.

Kopp, G.A., Morrison, M.J. & Henderson, D.J., 2012, Full-scale testing of low-rise, residential buildings with realistic wind loads, *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 104-106, pp. 25-39.

Mehta, K., 2013, Development of the EF-Scale for Tornado Intensity. Journal of Disaster Research, vol. 8(6), pp. 1034-1041.

Morrison, M.J., Henderson, D.J. & Kopp, G.A., 2012, The response of a wood-frame, gable roof to fluctuating wind loads, *Engineering Structures*, vol. 41, pp. 498-50.

Morrison, M.J., Kopp, G.A., Gavanski, E., Miller, C. & Ashton, A., 2014, Assessment of damage to residential construction from the tornadoes in Vaughan, Ontario, on 20 August 2009, *Canadian Journal of Civil Engineering*, vol. 41(6), pp. 550-558, doi: 10.1139/cjce-2013-0570.

Sills, D. M. L., McCarthy, P.J. & Kopp, G.A., 2014, Implementation and application of the EF-scale in Canada, *Extended Abstracts, 27th AMS Conference on Severe Local Storms,* Madison, WI, American Meteorological Society, Paper 16B.6.

Sparks, P.R., Schiff, S. D., and Reinhold, T. A., 1994, Wind damage to envelopes of houses and consequent insurance losses. Journal of Wind Engineering and Industrial Aerodynamics, vol. 53, pp. 145-155.

Stedman, D., 2012, Wind-tunnel tests of model vehicles to determine failure-inducing tornado wind speeds, 4th year thesis, Department of Civil & Environmental Engineering, University of Western Ontario, London, ON, Canada.

Wind Science and Engineering Center (WSEC), 2006, A recommendation for an Enhanced Fujita Scale. Texas Tech University, Lubbock, TX, USA.