9.1 **Birmingham U.K. Tornado: 28 July 2005**

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1. INTRODUCTION

On 28 July 2005, a tornado traveled through the eastern suburbs of Birmingham, U.K. injuring 39 people and damaging hundreds of buildings (Fig. 1). Within days after the event, the authors conducted a detailed ground damage survey. The purpose of the survey was to document the overall path length and width of the tornado as well as to determine its strength. In addition, the survey afforded the opportunity to compare building practices in the U.S. with those in the U.K. It was found that buildings in the damage path were constructed differently than conventional buildings in the U.S. One difference was the widespread use of loadbearing brick masonry walls in the U.K. as opposed to brick veneer systems in the U.S. However, the performance of the U.K. buildings was similar to that in the U.S. as tornadic winds exploited certain flaws in building construction particularly at the roof/wall connections. This paper will present the findings of our damage survey as well as discuss the meteorological conditions of the event.

2. WEATHER SITUATION

Analysis of surface weather features on 28 July 2005 indicated that the supercell that produced the Birmingham tornado developed along a warm front east of a surface low and moved northward toward Birmingham (Fig. 2). That morning, the weather conditions in Birmingham were typical for being north of a warm front. Skies were low overcast with periods of drizzle and light east winds. Surface temperatures north of the warm front ranged from 13 to 16°C at 1200 UTC. In the warm sector, south of the warm front, surface temperatures had increased to as much as 23°C at 1200 UTC with southerly winds. Local weather forecasts called for "blustery" conditions with no mention of severe weather.

Examination of satellite imagery on 28 July 2005 showed a classic comma-shaped cloud shield extending from a low-pressure center just south of Wales. Thunderstorms developed in an arc northeast of the low. Infrared imagery showed a channel of warmer temperatures (lower cloud tops) ahead of the developing thunderstorms (Fig. 3.)

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Figure 1. The Birmingham U.K. tornado. Photograph courtesy of Sasha Roberts.

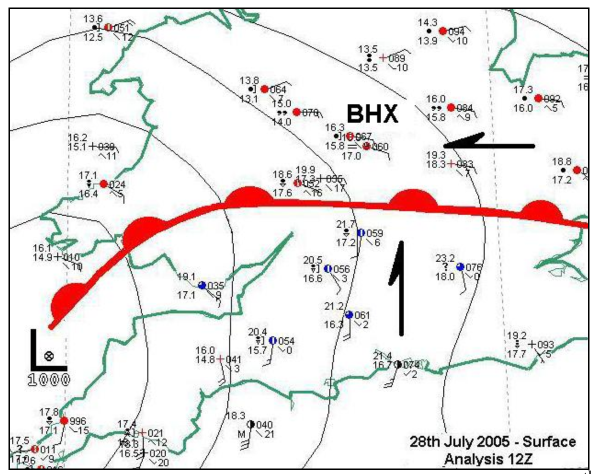

Figure 2. Surface weather map at 1200 UTC on 28th July 2005. Tornadic storm formed on a warm front that rapidly lifted to the north. Arrows indicate wind direction. The letters BHX indicate Birmingham.

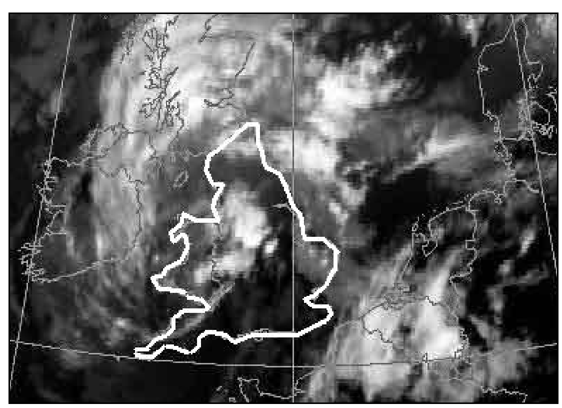

Figure 3. Infrared satellite imagery at 1400 UTC showing the development of thunderstorms over central England (outlined).

Analysis of radar reflectivity at 1430 UTC showed a line of thunderstorms extended across the Midlands region in the center of England. An intense storm was approaching Birmingham at this time (Fig. 4). Other storms developed farther to the southeast and at least one of them became tornadic as it crossed the warm front at Peterborough, about 120 km east of Birmingham.

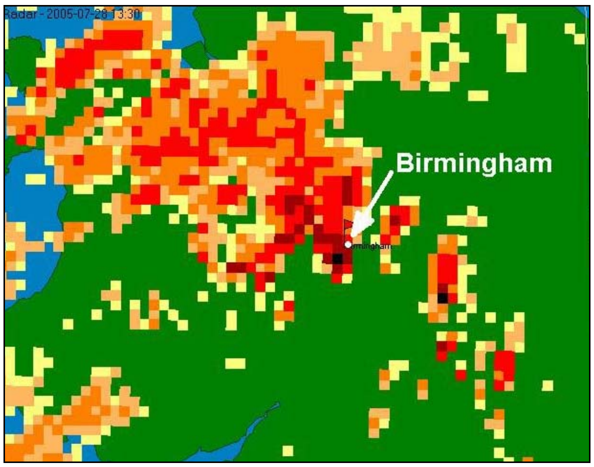

Figure 4. Composite radar reflectivity images at 1430 UTC showing an arc of thunderstorms across the region with an intense storm approaching Birmingham.

Upper air soundings of temperature, dewpoint, and wind were retrieved and studied for this event. The closest sounding stations to Birmingham were Nottingham (70 km northeast) and Larkhill (150 km to the south). The 1200 UTC sounding at Nottingham on 28 July 2005 showed a very moist environment, typical for being north of a warm front (Fig. 5). Surface winds were from the northeast but switched quickly to the south just above the ground then increasing to 50 kts at 500 mb. As expected, CAPE values were low for a sounding early in the day but with 20°C forecast temperatures, CAPE values would have increased to about 2000 J/kg in the warm sector. The Larkhill 1200 UTC sounding also showed a relatively moist environment in the warm sector (Fig. 6). Winds were unidirectional aloft but there was significant speed shear between the surface and 700 mb where winds increased from 15 to 50 kts.

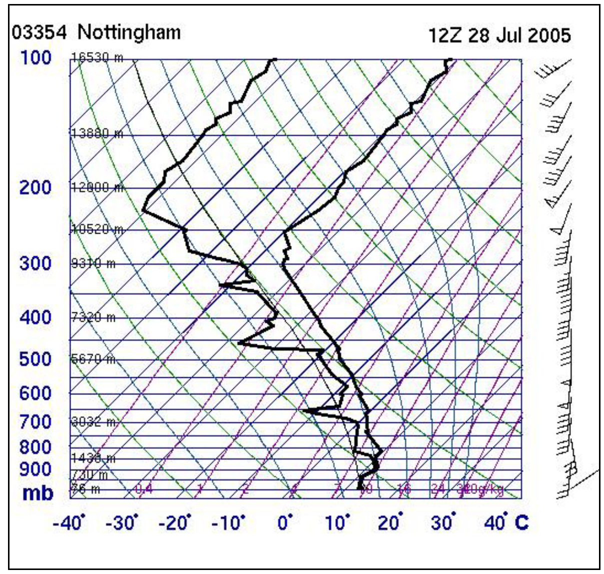

Figure 5. Sounding of temperature, dewpoint, and wind at 1200 UTC at Nottingham, about 70 km northeast of Birmingham, shows a sample of the environment north of the surface warm front.

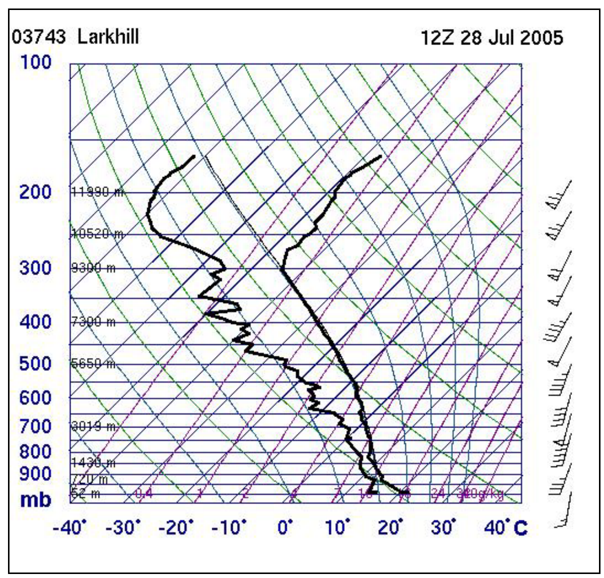

Figure 6. Sounding of temperature, dewpoint and wind at 1200 UTC at Larkhill, about 150 km south of Birmingham in the warm sector, south of the surface warm front.

3. THE DAMAGE SURVEY

The authors found the damage path extended about 11 km long and varied between 100 and 300m wide. The tornado tracked consistently along a heading 20 degrees east of north, and lasted about 20 minutes (Fig. 7). Tornado damage consisted primarily of displaced roof tiles and downed trees. However, some roofs were completely displaced and vehicles flipped or rolled in the worst damaged areas.

The tornado began south of the city center where sporadic roof and tree damage was noted around M-42, the main highway around the southern part of Birmingham. However, the first significant damage to buildings was found in the Kings Heath suburb about 5 km south of the city center. There, a roof was partially displaced and windows were broken at a supermarket. Residents indicated the tornado struck around 2:30 PM local time with little warning.

The damage path paralleled Ladypool Road, a densely populated area consisting mostly of two and three-story buildings with businesses on the first story. The most intense damage occurred in the Sparkbrook suburb where dozens of roofs were removed. Three residential buildings, each one block long, lost their roofs along Birchwood and Alder Roads (Fig. 8). Small trucks were tipped over and small cars were flipped or rolled (Fig. 9). The tornado reached its maximum intensity in this area, and was rated EF-2 on the Enhanced Fujita scale (see McDonald 2004) or T-4 on the TORRO scale that is used in Britain (see Meaden 1982). Maximum three-second winds that caused the damage were estimated to be between 50 and 60 ms^{-1}.

The tornado continued through an industrial area only 2.5 km east of the city center damaging or removing numerous metal or corrugated asbestos roofs. Then, the tornado weakened as it crossed the M-6, the highway leading east out of the city center. In all, about 300 buildings were damaged by the tornado, the most intense tornado in the area since 1931. There were 39 injuries, three serious, but amazingly no fatalities. City officials estimated the damage ranged from £30 to 50 million, the most costly tornado to date in the U.K.

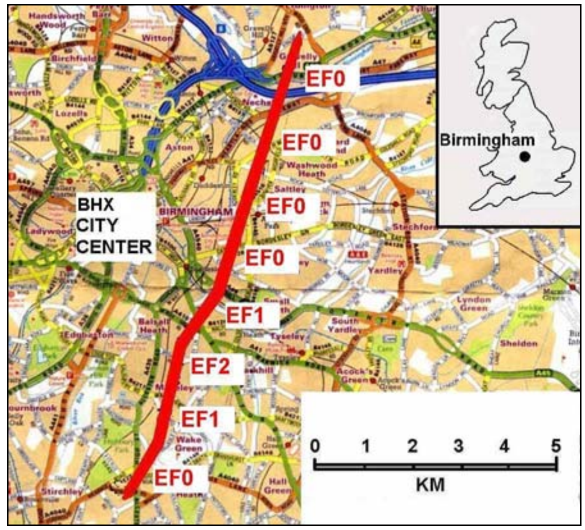

Figure 7. Damage path of the Birmingham U.K. tornado along with EF scale rating.

Figure 8. Among the most intense tornado damage observed were displaced roofs in the Sparkbrook subdivision only a few kilometers southeast of the Birmingham city center. Photograph courtesy of Adrian Pearman/Caters.

Figure 9. Car rolled over brick retaining wall causing dent in hood and came to rest against a building.

4. DAMAGE TO BUILDINGS

Most buildings damaged by the tornado had loadbearing brick masonry walls. Walls were double wythe in cross section with every sixth brick course turned perpendicular to the wall face in order to attach both wythes to each other (Fig. 10). Gable ends also were constructed with double wythe brick masonry. In essence, gable ends were free standing and had little resistance to lateral wind forces. As a result, the gable ends were susceptible to toppling in high winds leading to collapse of the roof (Fig. 11). Fortunately, such gable end failures were relatively rare due, in part, to the heavy weight of the slate and tile roofs that kept gable ends intact. But, falling masonry was quite hazardous crushing a number of cars. Some brick masonry chimneys fell into buildings, penetrated wood floors, and ended up on the first stories (Figs. 12 and 13).

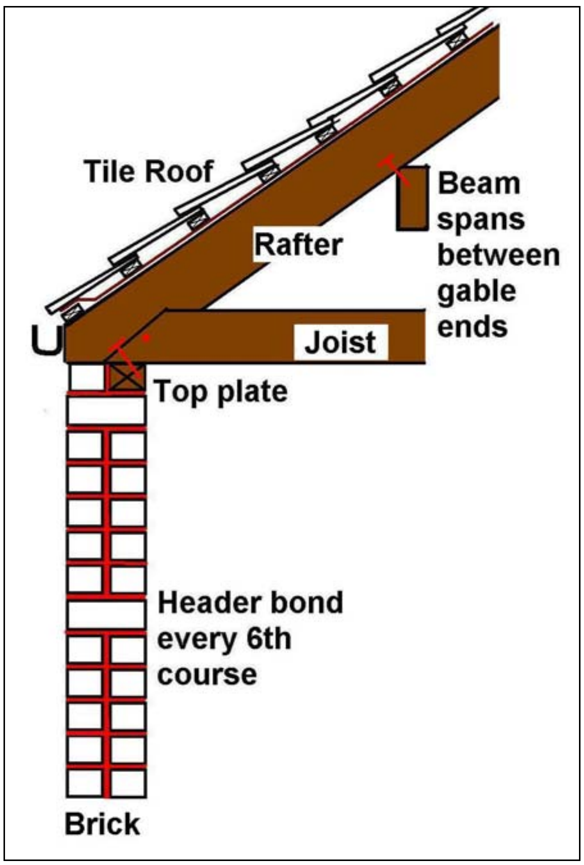

Figure 10. Cross section of typical loadbearing brick masonry building in the tornado damage path. Roof beam spanned between gable end masonry.

Figure 11. Collapsed brick masonry gable end. Dashed line indicates original roof profile.

Figure 12. Loss of brick masonry chimney (circled) along with roof tiles.

Figure 13. Chimney collapsed through upper floors ending up on the first story.

Roof structures were wood-framed. Generally, rafters and joists were nailed to wall top plates and the plates were anchored to the tops of the masonry walls. Rafters were nailed every three to four meters to wooden cross beams or purlins. The beams were then slotted into and supported by the brick masonry gable ends. Such construction worked well for carrying the heavy weight of the roof covering to the walls, however, these roof structures were susceptible to being uplifted by the wind. In some instances, the rafters pulled apart from the beams while in other instances, the beams were uplifted from the gable end masonry (Figs. 14 and 15). Only a few courses of brick had been placed over the slotted purlins, but this did little in the way of resisting wind uplift forces.

Close examination of the wall top plates revealed considerable corrosion of the nailed connections. In some instances, the nails broke or crumbled whereas in other instances the rafters pulled out of the wall top plates leaving the nails intact. Many of the buildings damaged by the tornado were old, some built more than one hundred years ago. However, some of the newer built buildings were built better with metal clips securing the rafters to the wall top plates.

Figure 14. Rafters were uplifted from the roof beams.

Figure 15. Roof beams were uplifted from slots or pockets in the gable masonry.

The vast majority of roofs were covered with quarried rock slates, concrete tiles, or clay tiles. The tops of the slates/tiles were nailed or hung on wood battens; the battens were secured to the rafters. Typically, an asphalt membrane underlayment had been sandwiched between the battens and the rafters to serve as a redundant water barrier. There was no solid roof deck. Wind uplifted the unanchored bottoms of the slates/tiles literally prying them from the battens. As a result, slates/tiles weighing up to 5 kg each became airborne missiles impacting buildings and vehicles downwind (Figs. 16 and 17).

Figure 16. Only the tops of double S-shaped concrete tiles were nailed to wood battens. Thus, the bottoms of the tiles could be lifted relatively easily by wind prying the tiles from the battens.

Figure 17. Impact marks on south side of residence from flying roof debris.

The most susceptible areas for removal of the roof coverings were along windward eaves, corners, rakes, and around chimneys where wind accelerated creating larger uplift forces (Figs. 18 through 20). Thus, it was possible to determine the wind direction from looking at the pattern of displaced roofing.

Figure 18. Slates removed from windward corner.

Figure 19. Clay tiles removed from windward rake.

Figure 20. Clay tiles displaced due to acceleration of wind around chimney.

5. SUMMARY

A strong tornado traveled through the densely populated eastern suburbs of Birmingham U.K. on 28 July 2005. The tornado injured 39 people and caused millions of pounds in damages, the costliest tornado in U.K. history to date. In many respects, this was a classic tornado situation with storms becoming tornadic along the warm front. However, there was little advanced warning of the tornado.

Within days after the event, the authors conducted a ground damage survey. We found the damage path extended about 11 km long and ranged up to 300 m wide. Some of the most intense damage occurred in the Sparkbrook subdivision where numerous roofs were removed. The authors rated the damage at EF-2 on the Enhanced Fujita scale and T-4 on the TORRO scale. Maximum three-second wind speeds were estimated at between 50 and 60 ms^{-1}.

We noted that buildings in the damage path were constructed differently than conventional buildings in the U.S. One difference was the widespread use of loadbearing brick masonry walls in the U.K. as opposed to brick veneer systems in the U.S. However, the performance of the U.K. buildings was similar to that in the U.S. as tornadic winds exploited certain flaws in building construction particularly at the roof/wall connections. Nailed connections pulled apart in tension or broke apart when corroded. Some of the buildings in the survey area were more than one hundred years old.

The vast majority of roof structures were built to take the weight of the heavy roof down through the brick masonry walls. In general, there was little in the way of lateral support for gable masonry or resistance of the roof structure to wind uplift. As a result, wind toppled loadbearing gables causing roofs to collapse. Also, the tops of some brick masonry chimneys had fallen into the buildings penetrating the floors ending up on the first stories. Falling masonry was definitely a hazard to people and it was amazing that more people were not injured.

Another problem was that the tops of roofing slates or tiles were nailed or hung on battens making them relatively easy to be uplifted by the wind. Some slates/tiles weighed 5 kg and became airborne impacting buildings and vehicles downwind. Patterns were noted in the locations of displaced roofing indicating the direction of the wind. Slates/tiles were most susceptible to being displaced at windward corners, eaves, and rakes as well as in areas where the wind accelerated around chimneys.

The authors wish to thank Pioneer Productions for funding the damage survey. References are available upon request.