2.2 WIND SPEEDS REQUIRED TO UPSET VEHICLES

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1. INTRODUCTION

Assignment of the Fujita Scale to wind damage relies primarily on damage to frame houses. This has been criticized as too subjective and prone to large errors in judgment. Variable building construction quality leads to errors in assignment of F-scale. A tornado or other severe wind that does not strike frame houses may be assigned an incorrect F-scale. These difficulties with the Fujita Scale are well known, yet the Fujita Scale has found wide acceptance and is in the public vocabulary.

Motor vehicles are abundant in the United States and are occasionally struck by severe winds. Some tornadoes and other wind storms may strike more vehicles than houses. For example, a tornado in open country may not hit any substantial building but strike several vehicles. In mobile home communities, where F-scale ratings above F2 are not assigned, the condition of vehicles may allow further refinement of the F-scale assigned. Thus, it could be useful to know how to assign or confirm F-scale damage ratings based upon effects of severe wind on vehicles.

The Fujita Scale does not describe wind effects on vehicles very well. This may be because cars are reported to be "easily tossed and destroyed" by tornadoes, as on the Storm Prediction Center's tornado safety page (www.spc.noaa.gov/faq/tornado/#safety), so no further description seems to be needed. Damage descriptions in the Fujita Scale vary somewhat, but generally state to expect that at F1 "moving automobiles pushed off the road," at F2 "cars blown off highway," at F3 "cars lifted off the ground," and at F4 "cars thrown some distances or rolled considerable distances" (McDonald 2001). The trouble with descriptions such as "moving autos pushed off the road" (F1) is that the auto may then be driven back onto the road and no longer evident to damage surveyors. Whether a moving auto is pushed off the road also depends on driver reaction and skill and elements of traction such as tires, pavement type, and pavement wetness. The difference between a car being blown off the road (F2) and lifted off the ground (F3) is unclear, unless the car blown off the road (F2) was not lifted off the ground.

We noticed that cars and pickups often remain upright at sites where mobile homes are destroyed. Based on those observations, we suggested that vehicles may be more stable than mobile homes in severe winds (Schmidlin and King 1995) and called for more research on the effects of tornadoes on vehicles (Schmidlin and King 1996).

Our purposes are (1) to review research on the wind speeds required to upset highway passenger vehicles, (2) to summarize our recent research on the topic, and (3) make recommendations for incorporating motor vehicles into the Fujita Scale damage descriptions. Further information is available in Schmidlin et al. (2002).

2. LITERATURE REVIEW

There is little information in the literature on the wind speeds required to upset highway motor vehicles. Fujita (1979) calculated that a wind speed of 39 m/s (87 mi/hr) at 5 m was required to "slide" a 1090 kg (2,400 lb) car off its resting position. He reported that unanchored cottages and mobile homes slide off their foundations at 32 m/s (72 mi/hr).

Wolde-Tinsae et al. (1985) reported on wind speed estimates from damage during the 28

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June 1979 tornadoes in Manson and Algona, Iowa. A 5,443 kg (12,000 lb) farm truck was displaced 100 m. They estimated that 80 m/s (179 mi/hr) was "the minimum wind speed necessary to aerodynamically uplift the truck" but called the credence level of the estimate "questionable."

Grazulis (1993, p. 104-105) reported the threshold wind speed needed for a "weightless state" to be 51 m/s (114 mi/hr) for a car weighing 1,820 kg (4,000 lb) and 39 m/s (88 mi/hr) for a mobile home weighing 17,800 kg (39,200 lb).

Saiidi and Maragakis (1995) reported on calculated minimum wind speeds to overturn common motor vehicles. They stated, "Due to their low profile and generally aerodynamic designs, automobiles are unlikely to pose the critical condition in terms of stability under wind loads" and they proceeded to report results only for high profile vehicles. They reported minimum overturning wind speeds (perpendicular to the vehicle) of 24 m/s (53 mi/hr) for a 5.5 m travel trailer, 29 m/s (65 mi/hr) for a 9 m motor home, 33 m/s (73 mi/hr) for a 13,600 kg semi-trailer, and 45 m/s (101 mi/hr) for a 5 m camper van. (Using their equations, we calculate a minimum overturning wind speed for a minivan to be 53 m/s (119 mi/hr)).

The literature is (1) sparse, (2) inconsistent in presenting "sliding", "overturning", and "uplift" wind speeds, and (3) based largely on equations for wind pressures and forces applied to vehicles of a given geometry.

3. RECENT RESEARCH

3.1. Instrumented Vehicles Exposed to Severe Winds

Two cases are known of instrumented storm chase vehicles exposed to high winds. Erik Rasmussen reported that a stationary 1993 Ford Tempo sedan in the VORTEX project was struck by a tornado near Alison, Texas, on 8 June 1995. The maximum wind speed averaged over 6 s at 3 m height was 44 m/s (98 mi/hr). The vehicle was not damaged and was not moved. Val Castor reported that his stationary 1990 full-size Chevrolet four-wheel drive pickup truck was struck by a rear-flank downdraft while he filmed a tornado near Lake Hefner, Oklahoma, on 13 June 1998. An anemometer over the truck and 3 m above the ground showed a gust of 47 m/s (105 mi/hr) from the left rear of the vehicle. The vehicle was not damaged and was not moved. The web site www.stormeyes.com/tornado/vehicles states that Brian Curran was in the NSSL1 mobile storm intercept vehicle, a 15-passenger van, when it was struck by a "100+ knot hot microburst" (52+ m/s, 115+ mi/hr) near Joy, Texas, on 14 May 1986 and "nearly rolled." Further details are not known.

3.2. Vehicles Parked Outside Houses Struck by Tornadoes

We studied 291 cars, minivans, vans, pickups, and SUVs parked within 10 m of houses that received F1 or greater damage from a tornado. These included nine tornadoes in seven states over the period 1994-1999. The Fujita Scale damage to the house was determined by visual inspection and assessment of changes to the house since the tornado struck. We asked the owners about any vehicles parked outside when the tornado struck and whether the vehicle was moved (>1 m) or tipped over by the wind.

The percentage of vehicles moved and the percentage tipped were not statistically different between F1 and F2 sites, nor between F3 and F4 sites, but there were differences between F2 and F3 sites. At sites with F1 (n=82) or F2 (n=83) damage to the house, 72% of the vehicles were not moved by the wind and 96% were not tipped over. At sites with F3 (n=105) or F4 (n=21) damage to the house, 50% of the vehicles were not moved by the wind and 82% were not tipped over. The percentage of higher-profile passenger vehicles (pickups, vans, and SUVs) moved or tipped by the wind was not significantly different from the percentage of automobiles moved or tipped (Schmidlin et al. 1998).

Based on these 291 cases of vehicles exposed to a tornado, we conclude that vehicles are rarely tipped over in F2 damage and about 1 in 5 vehicles are tipped over in F3 damage. Vehicles in our field study were not commonly "lifted off the ground" in F3 tornadoes, as the Fujita Scale description suggests.

3.3. Wind Tunnel Tests

The wind tunnel is a controlled environment with known wind speed and direction. The complex and largely unknown environment of a tornado, including gusts, turbulence, and debris, cannot be replicated in a wind tunnel. However, wind tunnel testing is commonly accepted and widely used to study the stability of vehicles (for example; Coleman and Baker 1994). We placed 1/6 scale models of a typical mid-size sedan and a minivan in a wind tunnel. Funding allowed testing of only two vehicle types, but these are two very common vehicle shapes and they roughly span geometry variations of other passenger vehicles, including pickups, large vans, and SUVs. Actual vehicle geometry, suspension compliance, and surroundings could impact their possibility for upset.

Measurements of lift, drag, and side forces and pitching, rolling, and yawing moments were recorded for each 5 degree yaw increment from 0 to 180 degrees wind direction. The models were tilted 5 degrees leeward to simulate body roll in the suspension under wind loads. The wind speed at which any one of the four tires became “weightless” was considered to be the minimum wind speed for “upset.” Our purpose was to use the results of the wind tunnel tests to corroborate the field study of 291 vehicles actually exposed to tornadoes, presented in section 3.2.

The sedan was most vulnerable to upset with wind from 140 degrees (rear quarter) when upset occurred at a wind speed of about 52 m/s (115 mi/hr). At other wind angles, upset occurred at wind speeds of 58 to 67 m/s (130 to 150 mi/hr).

The minivan was most vulnerable to upset with wind from 50 degrees (front quarter) and with wind from 140 degrees when upset occurred at about 58 m/s (130 mi/hr). At other wind angles, the minivan was upset at wind speeds of 72 to 81 m/s (160 to 180 mi/hr).

These are wind speeds directly on the vehicle at about 1 m above the ground. Using a log law wind profile with an open terrain roughness length of 0.01 m, the 52 to 81 m/s (115 to 180 mi/hr) range of minimum 1 m wind speeds required to upset these two vehicles converts to a 10 m wind range of 75 to 120 m/s (167 mi/hr to 267 mi/hr). This roughly brackets the current F3 and F4 ranges of wind speeds and supports our field study results showing that automobiles, pickups, vans, and SUVs are not commonly tipped over until well into the F3 damage category.

4. CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS

The few instrumented vehicles exposed to severe winds indicate that stationary vehicles in open terrain are not upset by winds of about 45 m/s (100 mi/hr). We are not aware of any instrumented vehicle that has been upset by wind. This is supported by our fieldwork on 291 vehicles actually exposed to a tornado. Fewer than 1 in 20 vehicles were upset at sites with F1 or F2 damage and fewer than 1 in 5 were upset in F3 damage. These results, in turn, are corroborated by wind tunnel tests on a sedan and minivan that showed a wind of 52 to 81 m/s (115 to 180 mi/hr) was required to upset the vehicles. This 1 m wind translates roughly to F3 and F4 estimated wind speeds at 10 m height.

Thus, it appears unlikely that a stationary vehicle will be upset by winds on the vehicle of less than 52 m/s (115 mi/hr). The probability of upset, and thus the percentage of vehicles upset, will increase as wind speed increases above 52 ms (115 mi/hr). At some wind speed, perhaps greater than 81 m/s (180 mi/hr), most vehicles in the wind field will be upset.

Based on this literature and research, we make the following suggestions for inclusion in Fujita Scale damage descriptions. These may be useful where vehicles are struck by a tornado but few buildings are struck, or where only mobile homes are struck and an F-scale rating above F2 is not possible without using this additional guidance on vehicles.

For F0 wind speeds of about 34 m/s (75 mi/hr), there should be no reference to vehicles in damage descriptions because they are not expected to be moved or tipped by the wind.

For **F1** winds speeds of about 43 m/s (95 mi/hr), **“Semi-trucks and other high profile trucks, trailers, and buses may be tipped over; cars, vans, and pickups are not tipped.”**

At **F2** wind speeds of about 56 m/s (125 mi/hr), **“Cars, vans, and pickups may be moved but fewer than 10% are tipped over.”**

At **F3** wind speeds of about 70 m/s (155 mi/hr), **“Cars, vans, and pickups are moved and 10% to 50% are tipped over. Vehicles that are tipped over may be rolled or lifted and thrown.”**

At **F4** wind speeds of about 90 m/s (200 mi/hr), **“More than 50% of cars, vans, and pickups are tipped over. Vehicles that are tipped over may be rolled or lifted and thrown.”**

The impact of severe wind on a single vehicle is not very informative, just as damage to a single building gives an uncertain F-scale rating. Data should be obtained on as many vehicles as possible with inquiries to residents about vehicles that are no longer at the sites (still being driven or in a repair shop).

Whether a severe wind will upset a stationary vehicle may depend on the vehicle weight and shape, progressive damage, impacts of debris, wind gusts, direction and duration of wind, and exposure. These inevitable concerns are similar to concerns and uncertainties experienced when assigning F-scales to damaged frame houses and other buildings.

5. ACKNOWLEDGEMENTS

This research was funded by the Quick Response Program of the Natural Hazards Center, University of Colorado, Boulder, and by the National Science Foundation, Geography and Regional Science Program (#9904402).

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