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EFFECTS OF INITIAL CONDITIONS ON THE FLIGHT OF PLATE-LIKE DEBRIS

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Abstract: Using the ‘failure’ model approach, the effects of initial conditions on the flight of plywood sheathing, roof tiles and asphalt shingles were investigated. In total thirty different configurations were examined by varying the wind angle, debris location on the roof, and surrounding buildings. All experiments have been completed and will be reported in the full conference paper. The major conclusion to date is that the initial failure depends on the global pressure induced by the wind acting on the building, while subsequent flight is based on local wind speeds on the roof and the aerodynamics of the debris element. Because of this, failures are sometimes observed without subsequent flight of the element even when there is substantial hold down force.

1 INTRODUCTION

Wind borne debris is the source of significant additional damage in extreme wind events. There have recently been several papers investigating the basic flight mechanics of compact, plate-like and rod-like debris. Tachikawa (1983) illustrated the complexity of the problem in his seminal experiments by illustrating that from an initial condition in a smooth, uniform flow many different flight patterns resulted from different initial angles of attack at release. Tachikawa's basic approach has been used by Lin et al. (2006) to develop criteria for debris impact speeds.

There have been relatively few studies on the effects of the initial conditions for debris flight. Wills et al. (2002) introduced the concept of the fixture strength integrity. They point out that for debris that is loosely held down, say under the objects own mass, that as it begins to fly it accelerates, lowering the relative velocity and the aerodynamic force, so that it can fall back to the ground. In contrast, for an object that is held down with significant resistance, once it breaks free it accelerates in a high speed flow and stays airborne for a much longer distance.

Of course, wind borne debris in real storms is also in a turbulent boundary layer flow. The role of turbulence has not been fully explored yet. Holmes looked at this with a simulated turbulent field for the flight of spheres and found that, while turbulence increased the scatter, he argued that it did not have significant effects.

In order to address both the role of initial conditions and turbulence, Visscher and Kopp (2007) examined the flight of aeroelastically-scaled plates mounted on the roof of a low-rise building model. These authors studied the flight of a 4 ft by 8 ft (full-scale equivalent) plywood panel held down with electromagnets to simulate the hold down force of the nails. The panel was mounted in a single location, near the ridge of the leeward roof surface along the centerline of the house model. A single (normal) wind direction was examined. These results showed that all of the possible modes of flight observed by Tachikawa can occur from the same nominal initial conditions when the plate is mounted in turbulent flow on a building surface. This was shown to have significance since the mode of flight dramatically altered the typical flight distances and speeds. In particular, when autorotation occurred, the flight distance was enhanced by the additional lift caused by the plate rotation when compared to plates which simply translated and fell in the wake of the house.

One of the points that appears to have been overlooked in the flight of wind borne debris is that the initial condition is set by the building aerodynamics while the flight immediately following failure is dependent on the aerodynamics of the debris element and the local velocity field. For a global roof failure, these are one and the same, but for sheathing, tiles and shingles there is a clear distinction between the flow (and surface pressure) field causing failure and the local aerodynamics governing flight. This has not been examined previously and is the motivation for the current work. Thus, the current work extends the work of Visscher and Kopp to other building configurations, initial panel locations, and wind directions for plywood sheathing, roof tiles and shingles in order to more precisely determine the role of the initial conditions for debris originating from low-rise buildings.

2 EXPERIMENTAL SET-UP

The experimental set-up uses the same approach as that for Visscher and Kopp (2007). The house model is the same as used previously and is a 1:20 scale model of the full-scale house being tested at the Three Little Pigs facility at the University of Western Ontario (UWO). The flow simulation in Boundary Layer Wind Tunnel 2 at UWO was of a relatively smooth open country terrain and is identical to that used in the earlier work. Figure 1 shows the experimental set-up used to generate the upstream boundary layer flow.

In the present tests, mass and mass-moment-of-inertia scaled models of a 4 ft by 8 ft plywood sheet, a typical roof tile and an asphalt shingle were made. Electromagnets were used two simulate the hold down force of the nails for the phywood sheathing, while passive magnets were used to provide the hold down force for the tiles and shingles. For the sheathing, the same loacation as in the earlier work was used and the effect of wind tunnel angle was examined. For the tiles and shingles, two wind angles (normal and quartering directions) were used for six different roof locations. In all cases, 30 repeated runs were obtained in each configuration in order to get statistically stable distributions of the flight distances and speeds. Further details on the set-up and configurations will be given in the full paper.

Figure 1. Photograph of the wind tunnel set-up looking upstream for (left) an isolated house in open country terrain, and (right) in a neighbourhood. The high speed camera is to the right of the house in order to obtain the video images of the initial failure and flight.

3 RESULTS

Figure 2 shows two strobe images of typical failures of the roof tile when it is placed near the ridge for a normal wind direction. Failure is often by overturning, but this is not always the case. There is significant variability in the process so that sometimes the tile landed on the leeward roof, in this configuration, for 5 of the 30 tests. Figure 3 depicts the typical landing locations of the tiles in this configuration. The wind speeds that caused the failure were also captured and will be presented in the full paper.

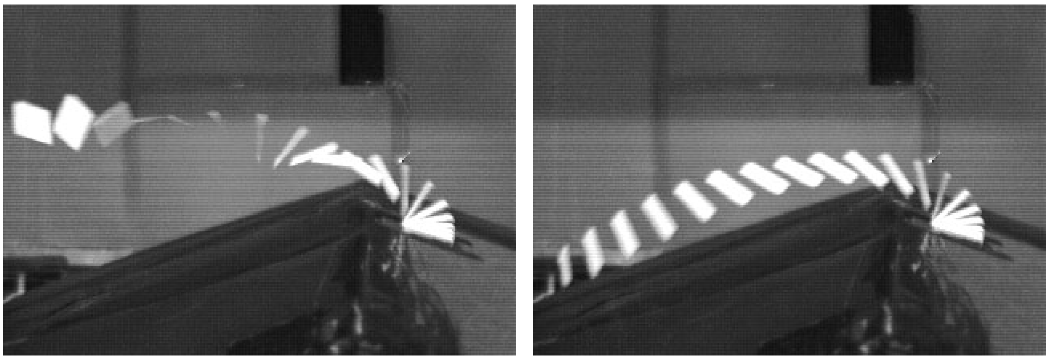

Figure 2. Strobe images taken from the high speed video of the initial flight patterns of the roof tiles for two experimental realizations under the same nominal initial conditions.

One of the interesting observations is that for some roof locations and/or wind angles, the debris elements would not fly. They would clearly be in pressure fields that would cause the failure, but they would begin to lift and would either fall back or overturn and land upside down, back on the roof. Since there was a hold down force used that was significantly larger than the mass of the object, this is not due to the mechanism described by Wills et al. (2002); rather, it must be due to an aerodynamic force coefficient which drops as the element begins to lift, or else the local wind speed around the element is too low to sustain flight. The latter could happen in the large separation bubble downstream of a separation at an eave edge or ridge. In this case, the flow near the surface is actually upstream and the failure-inducing pressure is caused by the large vortex/separation bubble. In several cases (not shown here), we actually observed debris elements moving upstream after failure and resting on the roof upstream of where it failed from. Thus, the local flow field on the roof is critical to the flight of wind borne debris.

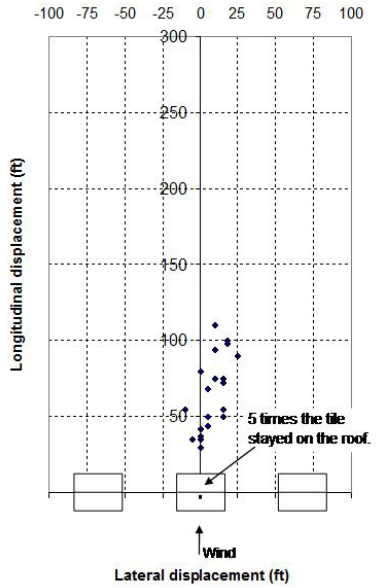

Figure 3. Landing locations in equivalent full-scale dimensions for a tile located near the ridge on the windward side of the roof on the building centreline for a normal wind direction.

4 SUMMARY

Preliminary data for one configuration of debris flight tests for a roof tile are presented. At present, all of the experiments have been concluded. The experimental database is significant with data from more than 30 configurations obtained, with about 30 realizations per case. These data are currently being processed to yield flight distances, landing locations, horizontal debris speeds near landing, and maximum height attained. These data will be included in the full conference paper and presentation. From our preliminary analysis of the data, it is clear the local flow field on the roof of the building is of critical importance for assessing the potential or a failed roof component to become wind borne debris, and that debris may not always originate from locations that have the largest suctions on the roof.

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