United States Department of Agriculture
Forest Service

Forest
Products
Laboratory

Research
Note
FPL–RN–0329

USDA Forest Products Laboratory's Debris Launcher

James J. Bridwell
Robert J. Ross
Zhiyong Cai
David E. Kretschmann

Abstract

Throughout the United States, hundreds of tornados and several hurricanes affect people's livelihoods each year. These natural disasters not only cause structural damage to property, they also cause numerous injuries, and regrettably, far too many deaths of people caught in their path. In an effort to increase the probability of surviving the strong winds and associated flying debris of these ferocious storms, a number of Americans are installing safe rooms in their homes.

In recent years, researchers at the U.S. Forest Service, Forest Products Laboratory (FPL), in Madison, Wisconsin, conducted a series of studies to examine the effectiveness of various materials and wall designs for use in such safe rooms. A key element of the research was the use of an air-pressure debris launcher that is capable of firing 2-in. by 4-in. lumber missiles into wall sections at speeds of approximately 100 miles per hour. This research note presents details of the launcher, summarizes test methods and results, and prescribes recommendations for future testing.

Keywords: Safe rooms, cross laminated timber, debris launcher

June 2013
Revised September 2017

Bridwell, James J.; Ross, Robert J.; Cai, Zhiyong; Kretschmann, David E. 2013 (revised 2017). USDA Forest Products Laboratory's debris launcher. Research Note FPL-RN-0329. Madison, WI: U.S. Department of Agriculture, Forest Ser-vice, Forest Products Laboratory. 14 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726–2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents

Conversion Table

English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
miles	1.6093	kilometers (km)
pounds (lb)	0.45359	kilograms (kg)

Acknowledgment

The authors acknowledge Dr. Joseph Murphy, who performed early tests, and his contribution to developing the equipment and test protocols.

USDA Forest Products Laboratory's Debris Launcher

James J. Bridwell, General Engineer
Robert J. Ross, Supervisory Research General Engineer
Zhiyong Cai, Supervisory Research Materials Engineer
David E. Kretschmann, Research General Engineer

Forest Products Laboratory, Madison, Wisconsin

Introduction

Throughout the United States, hundreds of tornados and a number of hurricanes affect people and homes each year, causing injury, death, and structural damage. Nearly every state east of the Rocky Mountains faces the possibility of devastating tornados, with the Midwest being particularly at risk (Fig. 1). Living along the gulf and east coasts offers little respite, as powerful hurricanes are apt to cause similar, and potentially more widespread, damage.

One particular danger of tornados and hurricanes is flying debris. When the envelope of a structure is punctured by debris, pressure changes from the wind can cause the structure to rapidly fail. In many areas, buildings were not built with resistance to debris in mind. However, with the impressive media coverage of recent disasters such as the devastating tornados in Joplin, Missouri, and Moore, Oklahoma, as well as Hurricanes Katrina and Sandy, greater numbers of home and small business owners are seeking to increase their probability of surviving a storm by voluntarily installing a "safe room" to shelter in.

A safe room is defined by the Federal Emergency Management Agency (FEMA) as "a space where you, your family, or friends and employees can survive a tornado or hurricane with little to no injury." Guidelines for safe room design are detailed in FEMA P-361, *Design and Construction Guidance of Community Shelters,* and FEMA P-320, *Taking Shelter from the Storm: Building a Safe Room Inside Your Home* (FEMA 2008a,b).

There are two main criteria for safe room design. The first is that the room's structural components must be able to withstand the basic wind load of the tornado or hurricane. The FEMA guidelines follow other major building codes such as International Building Code (IBC) 2006 and International Residential Code (IRC) 2006 in using American Society of Civil Engineers (ASCE) ASCE 7-05 criteria to establish wind loads. A map showing the four main wind zones specified in ASCE 7-05 is shown in Figure 2.

The second design criterion is that the safe room must have resistance to flying debris. A number of test criteria are used for debris impact resistance of overall building assemblies, for instance, the Florida Building Code (FBC), IBC, and ASCE 7-05 all reference large missile impact testing for building structures. FEMA P-320 and P-361 attempt to standardize safe room design by stipulating that testing of safe rooms shall be done in accordance with ICC-500, *Standard for the Design and Construction of Storm Shelters* (ICC: NSSA 2008). Table 1 is a list of design wind speed scenarios and corresponding missile speeds for tornado safe rooms according to ICC-500. With regard to hurricanes, ICC-500 requires a missile speed of 0.4 × design wind speed, whereas FEMA P-361 suggests a higher velocity value of 0.5 × design wind speed.

As part of their ongoing efforts to improve safe room design, researchers at the U.S. Forest Service, Forest Products Laboratory (FPL), conducted performance tests on a series of materials and wall designs that might be used in the construction of safe rooms. These tests were performed using a specially designed debris launcher that meets ICC-500 criteria of launching 2-in. by 4-in. lumber missiles at speeds of approximately 100 miles per hour (Fig. 3).

Debris Launcher Design Details

The main components of FPL's debris launcher are the pressure tanks, control valve, barrel, muzzle (Fig. 4), and instrument panel (Fig. 5b).

The pressure tanks are made of 52-in. long, 6-in. diameter schedule 40 PVC pipe and house the air needed to propel the missile to the target panel. The tanks are connected to the barrel by means of an electric solenoid control valve system (Fig. 5a). The control valve is a modified sprinkler valve that, via the instrument panel (Fig. 5b), allows the operator to remotely regulate air pressure in the tanks to ensure safety during testing.

The barrel of the debris launcher is made from a 150-in. long piece of 4-in.-diameter schedule 40 PVC pipe, which when housed in the mobile firing platform (Fig. 3), is supported every 24 in. by an aluminum block that is attached to the frame. These supports limit recoil and ensure accurate placement of the missile on the test target. Prior to firing,

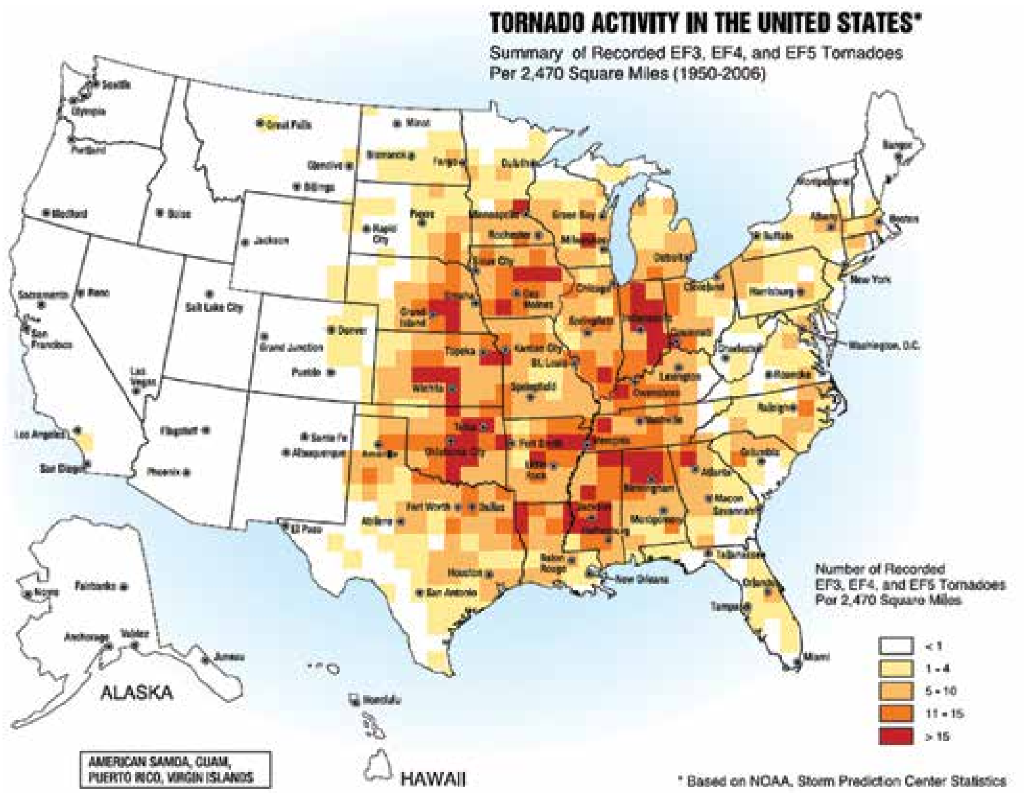


Figure 1. Map from FEMA P-320 showing the number of "Severe," "Devastating," and "Incredible" (categories EF3, EF4, and EF5, respectively) tornados in the United States from 1950–2006. Note the concentration in the Midwest, though many states are affected (FEMA 2008b).

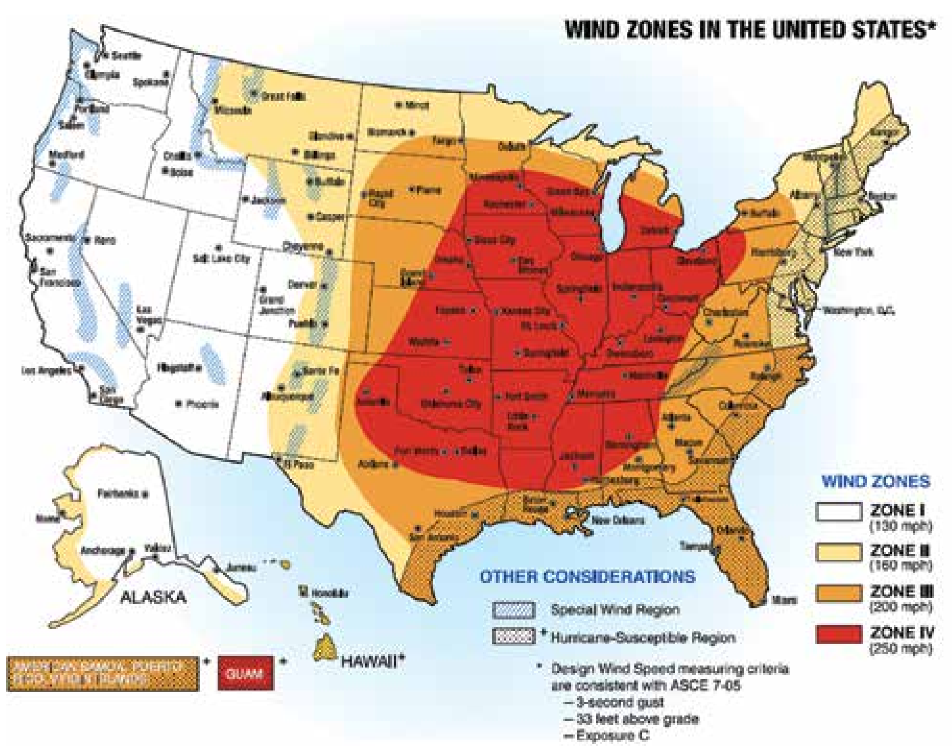


Figure 2. Design wind zones from FEMA P-320 based on ASCE 7-05 criteria. The zones mirror the locations of high intensity storms from Figure 1, with the addition of higher design requirements along the coasts due to hurricanes (FEMA 2008b).

Table 1. ICC-500 physical missile criteria for tornado shelters

Design wind speed (mph)	Missile dimensions (Nominal, in.)	Missile weight (lb)	Missile speed (mph)
130	2 by 4 sawn lumber	15	80
160	2 by 4 sawn lumber	15	84
200	2 by 4 sawn lumber	15	90
250	2 by 4 sawn lumber	15	100

Figure 3. Debris launcher housed in the mobile firing platform.

each lumber missile is inserted all the way to the rear of the barrel.

Attached to the front end of the barrel is the muzzle, which houses two electro-optical sensors. As the missile passes through the muzzle, the light across the first and then the second sensor is interrupted, sending electrical signals back to a conditioner in the instrument panel. The signal conditioner then computes and outputs a velocity measurement to the operator based upon the calibrated distance between the sensors and the time between signals.

Besides computing missile velocity, the instrument panel also serves as the control center for FPL's debris launcher. It enables the operator to route air to the pressure tanks, monitor tank air pressure, and activate the control valve to fire each missile all while maintaining a safe distance from any possible safety concern.

Missile Details

The typical missile used in the impact tests was a nominal 2-in. by 4-in. Southern Pine board that weighed between 15 and 15.5 lb and was between 144 and 146 in. long. No specifications were made on the desired grade of the missile; however, FEMA-361 (2008a) stipulates that missiles should contain no knots within 12 in. of the leading edge. Before being loaded into the barrel, each missile had a sabot of approximately the same circumference as the inside of the cannon barrel attached to its end to minimize the amount of air pressure lost (Figs. 6a,b). The sabot weighed 0.4 lb.

Panel Design

Test panels were designed to mimic the retrofitting of existing building structures to provide increased impact resistance to the debris propelled by tornados and hurricanes. The tests presented in this note used a wide array of materials including oriented strandboard (OSB), plywood, hardwood paneling, fiber-laminated hardboard, cross laminated timber (CLT), and bamboo composite panels.

OSB, plywood, hardwood, and CLT are common materials to the U.S. building industry and were chosen for their widespread use and availability. Bamboo was chosen for some panels because of its widespread availability, high strength–weight ratio, and superior ductility. The flexure and ductility characteristics of bamboo composites allow them to absorb high-impact energy while limiting catastrophic damage. Specific sizing and details of each panel can be found in the table in the Appendix.

Along with a variety of materials tested, there were four main configurations of panels. In the first configuration, panels were mounted to the front of a 6-in.-deep laminated lumber wall so that the missile impacted the panel first. In the second configuration, panels were mounted to the rear of the wall so that the missile struck the wall first. In the third configuration, panels were attached to a partially sheathed 2-in. by 4-in. stud frame, which itself was mounted to the wall (Fig. 7). The fourth configuration had the panel mounted to a steel frame in front of a laminated lumber backstop (Fig. 8).

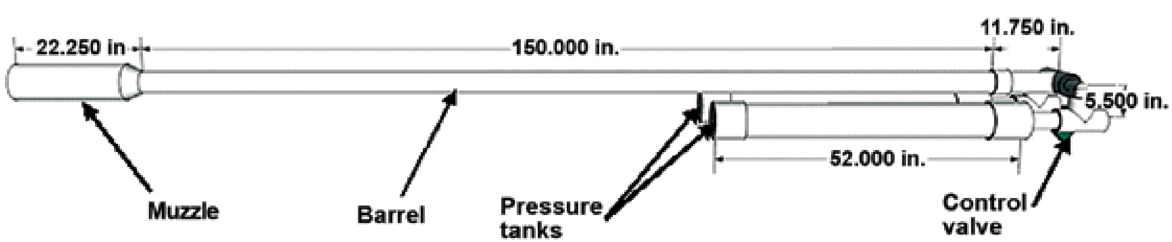


Figure 4. Details of the dimensions of the FPL debris launcher.

Figure 5. Debris launcher's (a) control valve and (b) instrument panel.

Test Method

During testing, the muzzle of the debris launcher was positioned approximately 16 ft from each target specimen. This distance protected the instrument from any rebound of the missile off of the panels and minimized loss of initial velocity as measured at the muzzle.

Even though the muzzle is 16 ft from the panel, the missile is only unsupported by the barrel over about a 4-ft horizontal distance, which is approximately 0.03 s of flight time. This results in a minimal vertical displacement (Fig. 9).

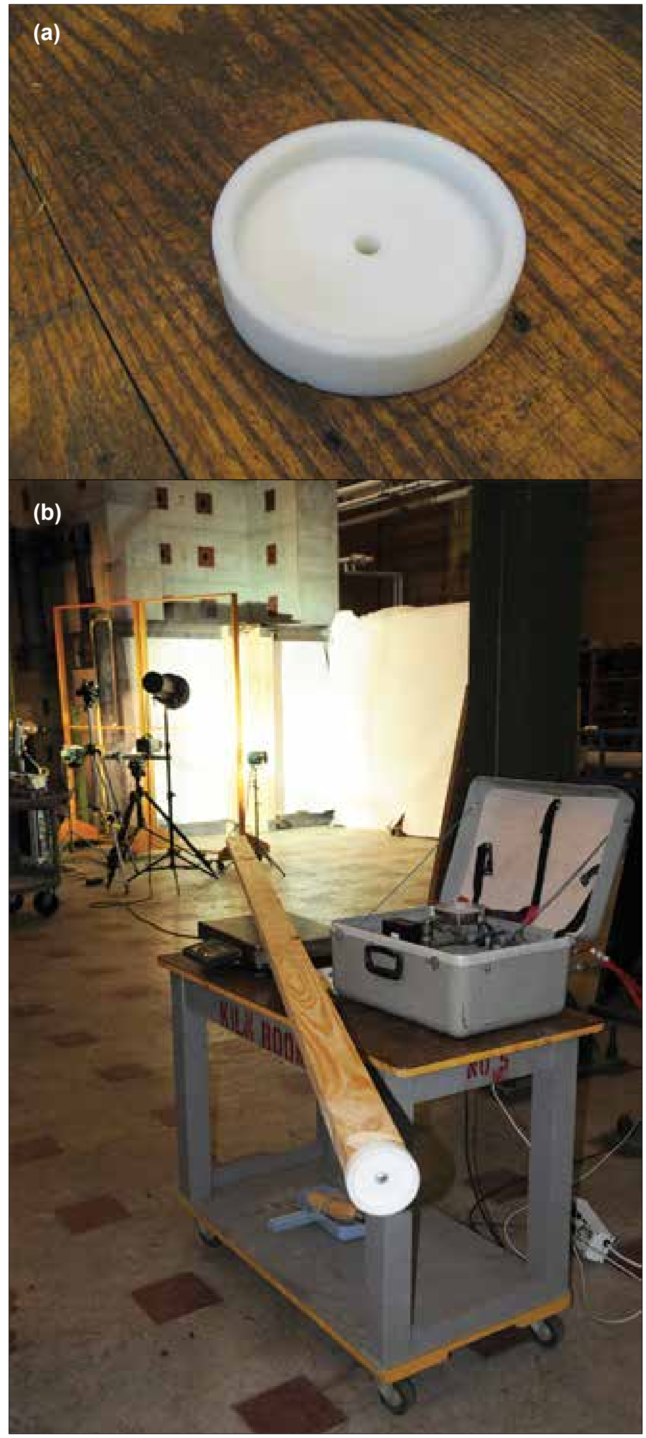


Figure 6. (a) Sabot and (b) missile with sabot attached at the trailing end.

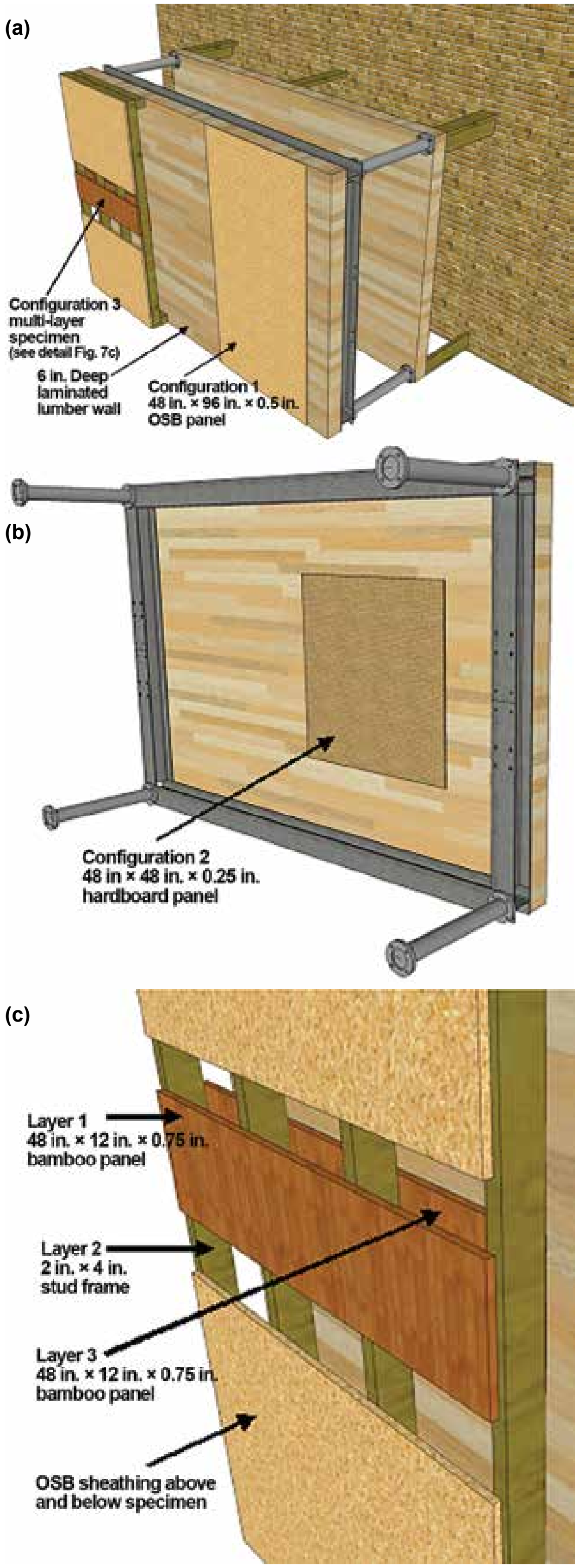


Figure 7. (a) Model of overall test setup and two panel configurations–Configuration 3 on the left and Configuration 1 on the right. (b) Model of Configuration 2 setup. (c) Detail of Configuration 3 setup.

Figure 8. Configuration 4–CLT panel with high-speed photography.

Unless otherwise noted, in each test the missile struck the horizontal and vertical center of the target panel. If the panel was fastened across studs, such as a multi-layer panel specimen, the missile contacted the panel between the studs. It was also assumed that the missile impacted the target within 5° of normal to the panel surface per requirements of ICC-500. This was later verified through pictures from the high-speed cameras. The general procedure for panel tests at FPL was as follows:

1. Mounted target panel.
2. Used a laser sight to aim the debris launcher barrel at the vertical and horizontal center of the panel. Laser sight was removed prior to loading each missile.
3. Loaded a sabot-attached missile into the barrel of the debris launcher. Positioned the missile all the way to the rear of the barrel.
4. Closed the control valve and pressurized the tanks to the desired air pressure.
5. From the instrument panel, activated the control valve and released pressure into the barrel.
6. Recorded missile velocity at the muzzle and panel results.

Test Results

Panel descriptions, mounting configurations, missile velocity, and damage reports obtained from testing of 30 individual panel sections can be found in the table in the Appendix. The figures below are examples of the results observed. Figure 10a shows a cross section of a panel that has been perforated by the lumber missile. Figure 10b shows a panel section that was able to withstand the force of the missile, although it did sustain considerable damage.

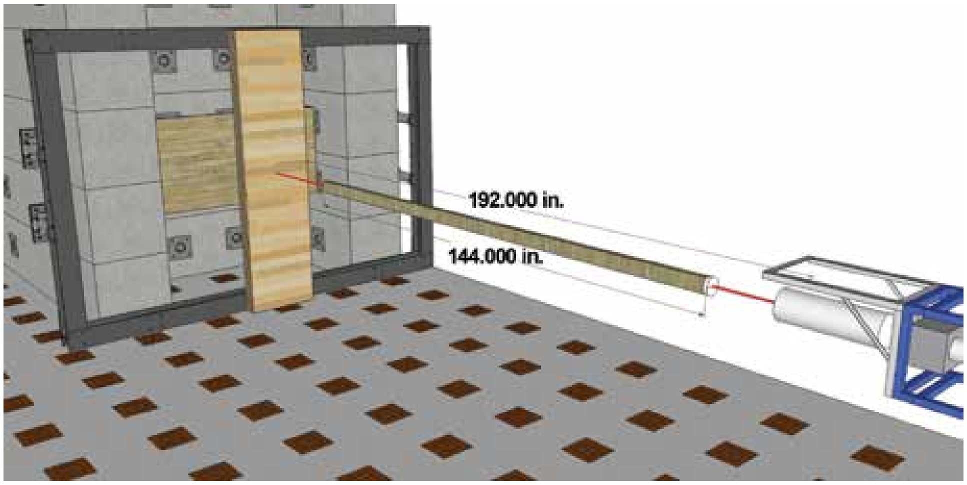


Figure 9. Model of Configuration 4 showing the distance from muzzle to panel and the trajectory of the missile.

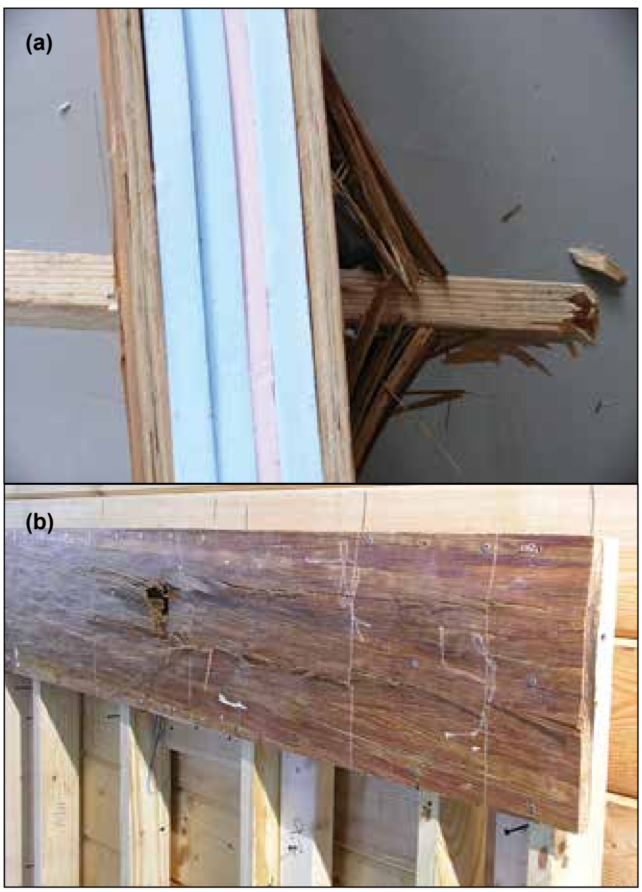


Figure 10. (a) Example of a missile perforating a sandwich panel section of bamboo and insulation. (b) Example of a bamboo panel damaged, but not perforated, by a missile.

Concluding Comments

The debris launcher at FPL has been shown to be an effective tool to simulate the flying debris produced by tornados and hurricanes. The cannon was capable of performing all ranges of testing sizes and speeds to meet building codes and FEMA guidelines. With further testing and refining of safe room design, home and small business owners will be more confident in their ability to survive the extreme weather events that threaten such a large portion of the country.

The following are some possible improvements to debris impact testing at FPL that would make the system even more effective:

- Continue efforts toward overall standardization of the impact test method.
- Include more detailed measurements and characteristics of panels and missiles for comparison.
- Develop and refine impact load modeling to better verify results.
- Include new materials and guidelines for designing target panels.
- Improve placement of high-speed cameras and implement strain-imaging systems in the contact area to better study the impact region.

References

ASCE. 2005. Minimum design loads for buildings and other structures: SEI/ASCE 7-05 (ASCE Standard No. 7-05). Reston, VA: American Society of Civil Engineers. 424 p.

FEMA. 2008. Design and construction guidance for community safe rooms. Second Edition. FEMA P-361. Washington, D.C.: Federal Emergency Management Association. 374 p.

FEMA. 2008. Taking shelter from the storm: building a safe room for your home or small business. Third Edition. FEMA P-320. Washington, D.C.: Federal Emergency Management Association. 46 p.

ICC: NSSA. 2008. ICC/NSSA Standard for the design and construction of storm shelters. Washington, D.C.: International Code Council: National Storm Shelter Association. 42 p.

Appendix—Panel description, mounting configuration, missile velocity, and damage report

Table 1. Test results from FPL debris impact study

Test No.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
1	No panel (The first missile was launched at the wall only.)	Wall only	Front	104	Full perforation, with 5-in. protrusion out of the back of the wall section. Wood shards airborne on impact.

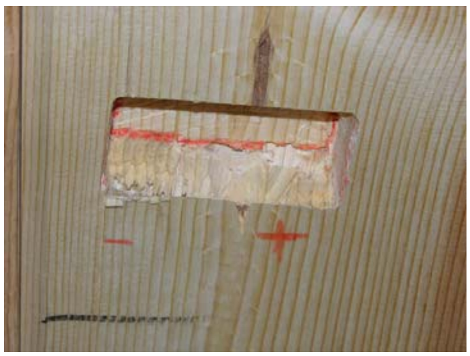

2	Layer 1: ½-in. oriented strandboard (OSB) Layer 2: 1-in. foam insulation Mounted to the wall with nails every 6 in. on the perimeter.	Wall only	Front	102	2-in. indentation in OSB, insulation, and face of the wall. The rear of the wall cracked and showed about 2-in. deformation. Wood shards airborne on impact.


3	Layer 1: ½-in. OSB Layer 2: 1-in. foam insulation Layer 3: ½-in. wire mesh Mounted to the wall with nails every 6 in. on the perimeter.	Wall only	Front	104	2-in. indentation in OSB, insulation and face of the wall. The rear of the wall was cracked.


Table 1. Test results from FPL debris impact study (continued)

Test No.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
4	Layer 1: ½-in. plywood panel Layer 2: 1-in. foam insulation standoffs inside the squares of a chain link fence Mounted to the wall with nails every 6 in. on the perimeter.	Wall only	Front	87	The missile pushed in the chain link and made a 2-in. indentation on the face of the wall. The rear of the wall was cracked and showed about a 2-in. deflection. Wood shards airborne on impact.


Test No.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
5	4-in. by 4-in. by ¼-in. ballistic fiber-coated hardboard. Mounted to the wall with 2-1/2-in. deck screws and 1-in. fender washers spaced at 4 in. on the perimeter and 6 in. in the interior.	Wall only	Rear	103	The missile caused a 2-in. indentation in the front of the wall, but there was no deflection at the rear. The ballistic panel appeared undamaged. No debris; some screws loosened.

Test No.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
6	4-ft by 4-ft by 1/4-in. tempered hardboard. Mounted to the wall with 2-1/2-in. deck screws and 1-in. fender washers spaced at 4 in. on the perimeter and 6 in. in the interior.	Wall only	Rear	103	The missile caused an indentation of about 2 in. in the front of the wall. A crack was present in the hardboard panel, but the deflection was less than 3 in. No debris; some screws loosened.

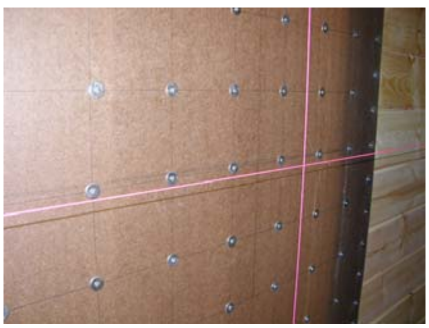



Table 1. Test results from FPL debris impact study (continued)

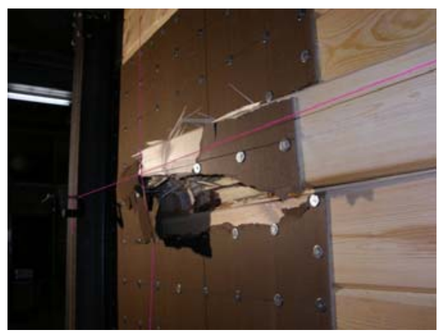
<table>
<tr><th>Test no.</th><th>Panel description</th><th>Wall/support frame</th><th>Panel location</th><th>Missile speed (mph)</th><th>Damage description</th></tr>
<tr><td>7</td><td>1-in. by 12-in. by 48-in. bamboo panel. Mounted to the support frame with screws to all support studs.</td><td>16-in. on-center (OC) wall frame with 2-1/2 in. of foam insulation in the void.</td><td>Front</td><td>103</td><td>The missile bounced off the panel but made an indentation in the face of the wall. No damage was seen on the rear of the wall.</td></tr>
<tr><td colspan="6"> </td></tr>
<tr><td>8</td><td>(2nd shot) 4-ft by 4-ft by 1/4-in. tempered hardboard. Mounted to the wall with 2-1/2-in. deck screws and 1-in. fender washers spaced at 4-in. on the perimeter and 6 in. in the interior.</td><td>Wall only</td><td>Rear</td><td>109</td><td>The rear of the wall deformed over 3 in. and dislodged the hardboard panel.</td></tr>
<tr><td colspan="6"> </td></tr>
<tr><td>9</td><td>2-ft by 2 ft by 1/2-in. plywood panel. Mounted to the wall with 2-1/2-in. deck screws and fender washers spaced at 4 in. on the perimeter and 6 in. in the interior.</td><td>Wall only</td><td>Rear</td><td>104</td><td>The missile caused a 2-in. indentation in the face of the wall. Cracks were present in the plywood panel. The rear of the wall had 1 in. or less deflection. No debris; some screws loosened.</td></tr>
<tr><td colspan="6"> </td></tr>
</table>

Table 1. Test results from FPL debris impact study (continued)

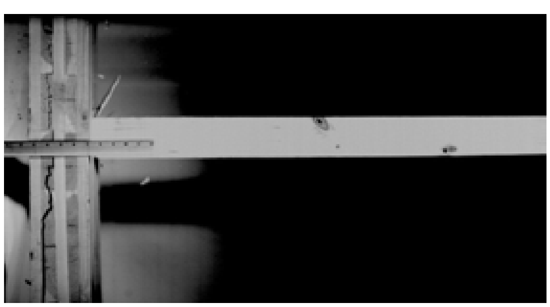
Test no.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
10	2-ft by 2-ft by ½-in. OSB panel. Mounted to the wall with 2-1/2-in. deck screws and fender washers spaced at 4 in on the perimeter and 6 in. in the interior.	Wall only	Rear	105	The missile caused a 2-in. indentation in the face of the wall. Cracks were present in the OSB panel. The rear of the wall had 1 in. or less deflection. No debris; some screws loosened.
	 				
11	¾-in. by 12-in. by 48-in. bamboo panel. The panel was machine made with generally uniform thickness. Mounted to the support frame with three rows of screws, 16-in. spacing.	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	105	The missile penetrated the panel and made an indentation in the face of the wall. No visible damage was done to the back side of the wall.
					
12	¾-in. by 12-in. by 64-in. bamboo panel. The bamboo panel was humanmade with longer fibers and had a varied thickness. Mounted to the support frame with three rows of screws, 16-in. spacing.	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	105	The missile perforated the panel and impacted the wall in the same area as Missile #14. There was damage to the back side of the wall in the form of a large crack.
	 				

Table 1. Test results from FPL debris impact study (continued)

Test no.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
13	(2nd shot) 4-ft by 4-ft by ¼-in. ballistic fiber coated hardboard. Mounted to the wall with 2-1/2-in. deck screws and 1-in. fender washers spaced at 4 in. on the perimeter and 6 in. in the interior.	Wall only	Rear	104	The missile caused a 2-in. indentation in the face of the wall, but there was no deflection at the rear of the wall. The ballistic panel appeared undamaged. No debris; some screws loosened.
14	(2nd shot) 2-ft by 2-ft by1/2-in. plywood panel. Mounted to the wall with 2-1/2-in. deck screws and fender washers spaced at 4 in. on the perimeter and 6 in. in the interior.	Wall only	Rear	107	Missile was fired 2 in. to the right of initial impact. Missile perforated the wall and blew out the plywood panel, protruding over 2 ft.
15	(2nd Shot) 2-ft by 2-ft by ½-in. OSB panel. Mounted to the wall with 2-1/2-in. deck screws and fender washers spaced at 4 in. on the perimeter and 6 in. in the interior.	Wall only	Rear	105	The missile caused a 2-in. indentation in the wall face. Damage in the OSB panel along the seam lines of the wall. The wall and OSB had less than 3-in. deflection.
16	5-in. by 5-in. by 36-in. live oak beam. Mounted to the support frame with rope and placed on supporting 2-in. by 4-in. extensions.	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target beam.	Front	109	The missile indented the front of the beam and cracked the rear, opposite of the impact area. Some of the frame studs were cracked and twisted.
17	12-in. by 1-1/2-in. by 60-in. laminated bamboo panel. Mounted to the support frame with screws to the supporting wall studs.	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	104	The missile perforated the bamboo panel and the wall. It protruded 24 in. through the back of the wall with lots of fraying on the panel. The wall had been weakened by previous strikes in the area.
18	12-in. by 1-in. by 60-in. laminated bamboo panel. Mounted to the frame with screws to the supporting wall studs.	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	107	The missile perforated the bamboo panel and the wall. The bamboo panel had a cleaner penetration hole and less frayed fibers than the panel used with Missile #17.
19	4-ft by 7-ft by ½-in. OSB panel. Mounted to the wall with 2-1/2-in. deck screws and fender washers spaced at 4 in. on the perimeter and 6 in. in the interior. The panel was fastened in the center 3-ft by 4-ft section only.	Wall only	Rear	104	The missile caused a 1-1/2-in. indentation in the face of the wall. Cracks in the OSB panel were present. The rear of the wall had 1 in. or less deflection.
20	Layer 1: 12-in. by 1-in. by 60-in. pressed bamboo board Layer 2: 2-in. by 4-in. stud frame, 16-in. OC with Styrofoam insulation in the voids Layer 3: 12-in. by 1-in. by 60-in. pressed bamboo board	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	103	The missile perforated both of the bamboo boards and the Styrofoam. The penetration created a clean entrance hole while the rear had fibers frayed 8 in. from either side of the hole.
21	Layer 1: 12-in. by 1-in. by 60-in. pressed bamboo board with nylon cargo straps on the rear face Layer 2: 2-in. by 4-in. stud frame, 48-in. OC with Styrofoam insulation in the void Layer 3: 12-in. by 1-in. by 60-in. pressed bamboo board	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	102	The missile perforated the front bamboo board, pulled the cargo straps, and crushed the Styrofoam. The rear bamboo board was undamaged. Three of four frame studs were damaged.

Table 1. Test results from FPL debris impact study (continued)

Test no.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
22	Layer 1: 12-in. by ¾-in. by 48-in. high-quality (HQ) laminated plywood board Layer 2: 12-in. by ¾-in. by 48-in. HQ laminated plywood board Layer 3: 2-in. by 4-in. stud frame, 16-in. OC Layer 4: 12-in. by ¾-in. by 48-in. HQ laminated plywood board	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	102	The missile perforated all three of the plywood boards. The penetration created a clean entrance hole through all three plywood boards.
23	Layer 1: 12-in. by ¾-in. by 48-in. HQ laminated plywood board with nylon cargo straps on the rear face Layer 2: 12-in. by ¾-in. by 48-in. HQ laminated plywood board Layer 3: 2-in. by 4-in. stud frame, 48-in. OC Layer 4: 12-in.by ¾-in. by 48-in. HQ laminated plywood board	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. The frame was mounted to the wall with 4-in. by 4-in. blocks at the top and bottom. The frame had OSB sheathing above and below the target panel.	Front	103	The missile perforated the front plywood board, pulled the straps, and broke the second board. It did not damage the rear board. The frame sustained major damage to the two center studs.
24	Layer 1: 12-in. by ¾-in. by 48-in. HQ laminated plywood with nylon cargo straps on the rear face Layer 2: 2-in. by 4-in. stud frame, 16-in. OC Layer 3: 12-in. by ¾-in. by 48-in. HQ laminated plywood board	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. Double studs were used in the center two wall cells and single studs on the perimeter. The top and bottom 3 ft were sheathed with ¾-in. OSB.	Front	105	The missile perforated the front plywood board, pulled the cargo straps, and protruded through the second board. The frame itself had no significant damage.
25	Layer 1: 12-in. by 2/3-in. by 48-in. Laminated Storm Blocker® board Layer 2: 2-in. by 4-in. stud frame, 16-in. on center	4-t by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. Double studs were used in the center two wall cells and single studs on the perimeter. The top and bottom 3 ft were sheathed with ¾-in. OSB.	Front	102	The missile perforated the Storm Blocker® panel in the strike zone, struck the wall, and bounced back. The frame did not appear to suffer any significant damage.
26	Layer 1: 12-in. by 1-in. by 48-in. bamboo composite board with nylon cargo straps on the rear face Layer 2: 2-in. by 4-in. stud frame, 48-in. OC Layer 3: 12-in. by ¾-in. by 48-in. HQ laminated plywood board	4-in. by 8-in. frame of 2-in. by 6-in. studs, 16-in. OC. Double studs were used in the center two wall cells and single studs on the perimeter. The top and bottom 3 ft were sheathed with ¾-in. OSB.	Front	103	The missile perforated the bamboo board, pulled the straps in the strike zone, broke through the plywood board, and struck the wall. The frame did not appear to suffer any significant damage.
27	Layer 1: 12-in. by ¾-in. by 48-in. HQ laminated plywood with nylon cargo straps on the rear face Layer 2: 12-in. by ¾-in. by 48-in. HQ laminated plywood Layer 3: 2-in. by 4-in. stud frame, 48-in. OC Layer 4:12-in. by ¾-in. by 48-in. HQ laminated plywood	4-ft by 8-ft frame of 2-in. by 6-in. studs, 16-in. OC. Double studs were used in the center two wall cells and single studs on the perimeter. The top and bottom 3 ft were sheathed with ¾-in. OSB.	Front	105	The missile perforated all layers of the plywood boards and pulled the straps in the strike zone and struck the wall. The frame did not appear to suffer any significant damage.
28	Five ply Douglas-fir cross laminated timber panel. Each lamination was 1-in. thick.	2-in. by 8-ft panel attached to steel frame	Front	103.5	The 15.3-lb., 2-in. by 4-in. missile caused a 1-1/2-in. indentation in the front of the panel. The fourth lamination failed perpendicular to grain. There was some deflection at the rear but it was not permanent and no debris flew from the back side of the panel.



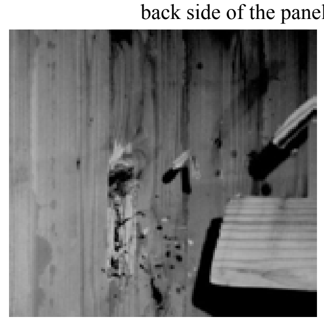


Table 1. Test results from FPL debris impact study (continued)

Test no.	Panel description	Wall/support frame	Panel location	Missile speed (mph)	Damage description
29	Five ply Douglas-fir cross laminated timber panel. Each lamination was 1-in. thick.	2-ft by 8-ft panel attached to steel frame	Front	102.0	The 15.4-lb, 2-in. by 4-in. missile caused a 15/16-in. indentation in the front of the panel. The fourth lamination failed perpendicular to the grain. No debris flew from the back of the panel, but there was a permanent deflection on the rear of the panel.
	 				
30	Five ply Douglas-fir cross-laminated timber panel. Each lamination was 1-in. thick.	2-ft by 8-ft panel attached to steel frame	Front	103.4	The 15.6-lb., 2 by 4 missile caused a 15/16-in. indentation in the front of the panel. The fourth lamination failed perpendicular to grain. There was limited deflection at the rear but it was not permanent and no debris flew from the back of the panel. Missile shattered.