Explosive Testing for 3M Corporation

Summary Report

Prepared by:
Applied Research Associates, Inc.
Security Engineering Group
119 Monument Place
Vicksburg, MS 39180

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Prepared for:
Mr. Ken Smith
3M Corporation
Consumer Safety and Light Management Dept.
3M Center, Building 207-1W-08
St. Paul, MN 55144

EXECUTIVE SUMMARY

In response to the heightened concern about terrorism, the US Government and private industry are developing and testing new technologies to mitigate hazards to people in the vicinity of a terrorist bombing. Propelled by the forces of a terrorist bomb, glass fragments cause large numbers of serious injuries.

The US General Services Administration (GSA) developed comprehensive security criteria (GSA Security Criteria, October 8, 1997) that includes physical security, electronic security, and many other criteria for blast considerations. These criteria formed the basis for the Interagency Security Committee (ISC) Security Criteria (October 31, 2003). The GSA has indicated that manufacturers must test their window products against the criteria to evaluate the performance of these products in blast if they want to be considered for use in GSA buildings. Actual window designs are then performed with the GSA computer program ***WINGARD*** (Window Glazing Analysis Response and Design).

The 3M Corporation commissioned ARA to perform two open-air high-explosive tests on September 16-17, 2004. Four window systems were evaluated in each test. The test used the GSA standard test protocol (GSA-TS01-2003) which is included in Appendix A. The window systems were mounted in enclosed concrete reaction structures. The response of the window systems was captured with high-speed film and still photography. An exterior, high-speed camera and an exterior, normal-speed video camera were used to capture the view of the structure and the explosive detonation for the test. The reaction structure was instrumented with pressure gauges to measure the exterior reflected pressure on the specimens and the internal pressure in the structures.

The charge size for all tests was 600 lb of Ammonium Nitrate and Fuel Oil (ANFO), which is equivalent to 500 lb of TNT. The standoff distance to the structure for both of the tests was 165 ft. The ANFO charge was constructed as a 1:1 cylinder and was detonated at ground level.

A test matrix was developed to explore the effect of various security film thickness and film attachment combinations on the windows' response. The nominal window size for the tests was 4 ft by 5-1/2 ft. The glass types used for the two tests consisted of both annealed glass (AG)

and thermally tempered glass (TTG). The windows were tested in typical commercial aluminum frames.

The ISC performance conditions for windows are presented graphically in the Figure E.1 and described in the Table E.1 below. The ISC approach compares potential hazards based on the type and location of glass fragments interior and exterior to the test cubicle. These criteria indirectly reflect the velocity (hence hazard level) of fragments based on their distance from the original window position.

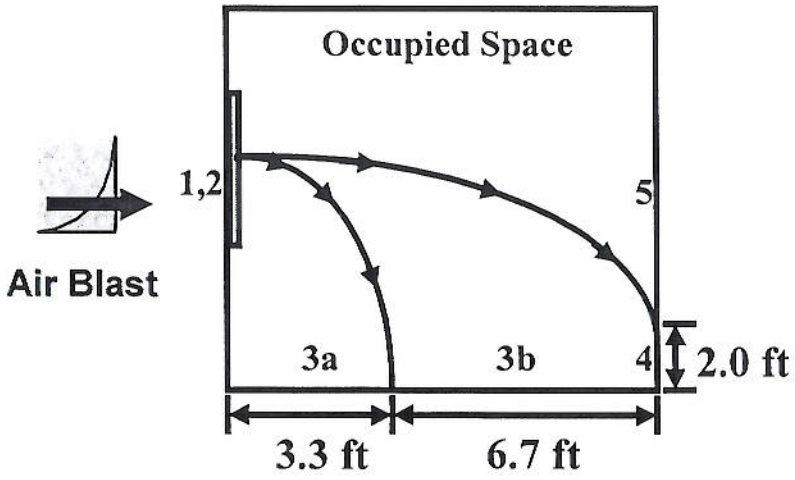

Figure E.1. Glazing protection levels based on fragment impact locations.

Table E.1 Glazing protection levels based on fragment impact locations.

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
4	Medium	Medium	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 ft. from the window at a height no greater than 2 ft. above the floor.
5	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor.

The results of the tests are documented in the following tables and photographs. Properly designed and installed windows can be developed to provide a high level of protection against the GSA Level C (ISC Medium) loading of 4 psi and 28 psi-msec. Quality control during installation is very important and can drastically affect window response.

At the request of 3M Corporation, ARA collected and weighed glass fragments landing within performance condition regions 3a and 3b inside of each test structure. While this information is not required to meet the GSA test requirements, 3M Corporation needed this information to meet specific project requirements. The fragment data is included in the Appendix D.

Table E.2. TEST 1 SUMMARY

Date:	16 September 2004
Nominal Charge Weight, lb ANFO:	600 lb
Standoff to structure, ft:	165 ft.
Avg. Measured Peak Pressure, psi:	4.88
Avg. Measured Positive Impulse, psi-msec:	37.45
Time of Detonation:	4:16 pm
Ambient Temperature, deg F:	88.2

	Window 1	Window 2	Window 3	Window 4
Specimen Description	1/4" monolithic AG, 4-sided wet-glazed attachment S50NEAR400 Ultraflex	1/4" monolithic AG, 4-sided wet-glazed attachment S50NEAR400 Ultraflex	1/4" monolithic AG, 4-sided wet-glazed attachment SCLARL400 Ultraflex	1/4" monolithic AG, 4-sided wet-glazed attachment SCLARL400 Ultraflex
Damage Description	Glazing cracked, pulled out of frame, and landed 119" outside of structure. No visible damage to frame.	Glazing cracked, pulled out of frame, and landed 148" outside of structure. Snap-in glazing stop along bottom of frame separated from frame and remained attached to glazing (landing outside of structure).	Glazing cracked, pulled out of frame, and landed 146" outside of structure. Snap-in glazing stop along bottom of frame separated from frame and remained attached to glazing (landing outside of structure).	Glazing cracked, pulled out of frame, and landed 23" outside of structure. Snap-in glazing stop along bottom of frame separated from frame and remained attached to glazing (landing outside of structure).
Window Glazing Response	Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.	Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.	Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.	Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.
Hazard Level	Low	Low	Low	Low
Protection Level	High	High	High	High
Performance Condition	3b	3b	3b	3b

Test Notes:
1) All window units had a 1/2 inch minimum bite.
2) Windows were mounted in typical aluminum frames: clear opening = 46.00 inches x 64.00 inches.
3) AG = annealed glass.
4) Witness panels were located 120 inches behind window.
5) The test bed is situated at an altitude of 6200 ft above sea level.
6) Window edges (left and right) are based on a person standing to the exterior of the window looking inward.
7) All wet glazed systems contained 1/2 inch (glazing edge) x 3/4 inch (frame edge) silicone contact lengths.
8) 3M Ultraflex was used for all wet-glazed attachments.
9) Windows were mounted by "sandwiching" the frame between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. 1-inch long #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame.

Table E.3. TEST 2 SUMMARY

Date:	17 September 2004
Nominal Charge Weight, lb ANFO:	600 lb
Standoff to structure, ft:	165 ft.
Avg. Measured Peak Pressure, psi:	5.00
Avg. Measured Positive Impulse, psi-msec:	37.38
Time of Detonation:	10:54 am
Ambient Temperature, deg F:	82.9

	Window 1	Window 2	Window 3	Window 4
Specimen Description	IGU: 1/4" monolithic AG (outer), 1/2" air gap, 1/4" monolithic AG (inner), 4-sided wet-glazed attachment (Ultraflex), Ultra600 film with vertical butt-splice down center of pane.	IGU: 1/4" monolithic TTG (outer), 5/8" air gap, 1/4" monolithic TTG (inner), daylight applied Ultra600 film with vertical butt-splice down center of pane.	1/4" monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SCLARL400 film (with deflection indicator dots).	1/4" monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SH8+RE35NEARL film
Damage Description	Exterior pane shattered and landed outside of structure. Interior pane cracked and separated along vertical window film seam, but glazing remained in frame. Wet-glazed attachment remained intact. No visible damage to frame.	The exterior pane shattered with fragments falling both inside and outside of the test structure. Interior pane cracked, separated along vertical window film seam, pulled out of frame and landed outside of test structure. Half of the interior pane landed 10 1/2" outside of test structure and the other half landed 34" outside of test structure. A piece of frame entered the structure and appeared to impact the witness panel.	Glazing cracked and pulled out of frame along the right jamb, head and sill. Window film tore along the left jamb which left the majority of the glazing hanging outside of the test structure just below the window opening. No visible damage to frame.	Glazing cracked, pulled out of frame, and landed 145" outside of test structure. No visible damage to frame.
Window Glazing Response	Large glass fragments landed outside of structure. Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.	Large quantities of glass fell both inside and outside of test structure. Glass fragments landed in 3a – 3b region inside of test structure. One impact on witness panel appeared to be caused by a piece of window frame that entered test structure.	Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.	Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.
Hazard Level	Low	Low	Low	Low
Protection Level	High	High	High	High
Performance Condition	3b	3b	3b	3b

Test Notes:

1) All window units had a 1/2 inch minimum bite.
2) Windows were mounted in typical aluminum frames: clear opening = 46.00 inches x 64.00 inches.
3) AG = annealed glass, TTG = thermally tempered glass.
4) Witness panels were located 120 inches behind window.
5) The test bed is situated at an altitude of 6200 ft above sea level.
6) Window edges (left and right) are based on a person standing to the exterior of the window looking inward.
7) All wet glazed systems contained 1/2 inch (glazing edge) x 3/4 inch (frame edge) silicone contact lengths.
8) 3M Ultraflex was used for all wet-glazed attachments.
9) Windows were mounted by "sandwiching" the frame between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. 1-inch long #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame.