Explosive Testing for 3M Corporation

Final Report

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PREFACE

Applied Research Associates, Inc. (ARA) conducted high-explosive tests on September 16-17, 2004, to evaluate the glass fragment hazard mitigation characteristics of window systems developed by the 3M Corporation. Four window systems were used in 2 tests; this report documents the results of the explosive testing of the eight window systems for the 3M Corporation.

The test was performed at the Energetic Materials Research and Testing Center (EMRTC) located in Socorro, New Mexico. The test site is jointly operated by the New Mexico Institute of Mining and Technology and Applied Research Associates, Inc.

The Security Engineering Group of ARA provided test structures, test design, test planning, and documentation of the results. Mr. James T. Brokaw was the principal investigator and the field test engineer for this effort. The ARA team assigned to this project also included Mr. Kenneth W. Herrle and Mr. Marcus D. Taylor. The Shock Physics Division and Rocky Mountain Division of ARA, under the direction of Mr. Donald Cole and Mr. Larry Brown, respectively, were responsible for test bed preparation, construction, test instrumentation, data collection, and test execution.

This work was sponsored by 3M Corporation. The support and effort provided by Mr. Ken Smith (3M Corporation's point of contact) are greatly appreciated.

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.

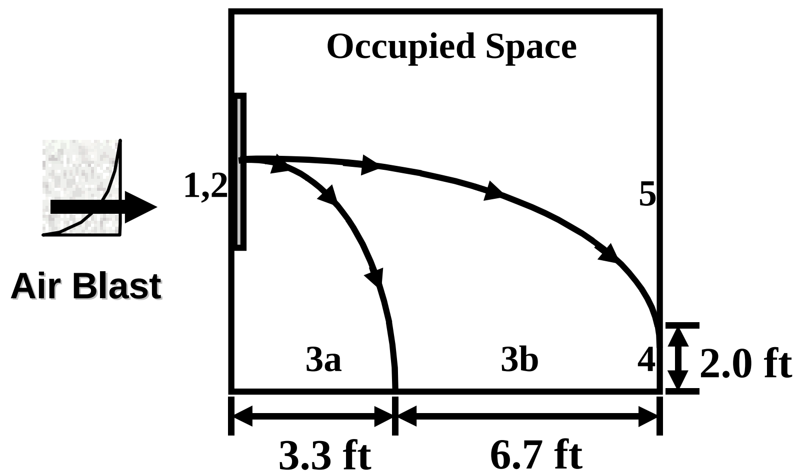


Figure E.1. Glazing protection levels based on fragment impact locations.

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.

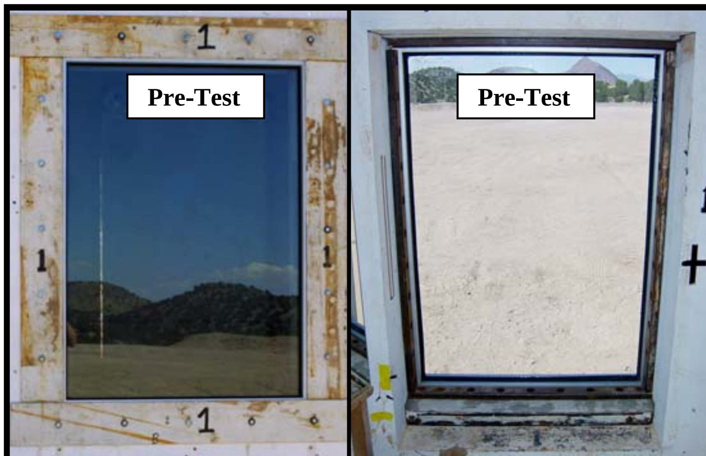
At the request of 3M Corporation, ARA collected and weighed glass fragments landing within performance condition regions 3a and 3b inside of each test structure. While this information is not required to meet the GSA test requirements, 3M Corporation needed this information to meet specific project requirements.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

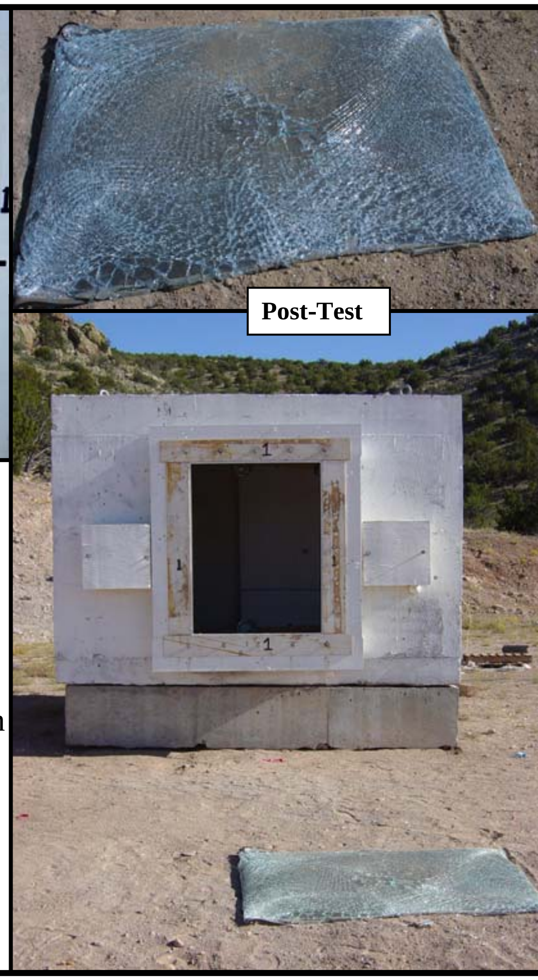
Table E.2. TEST 1 SUMMARY

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.

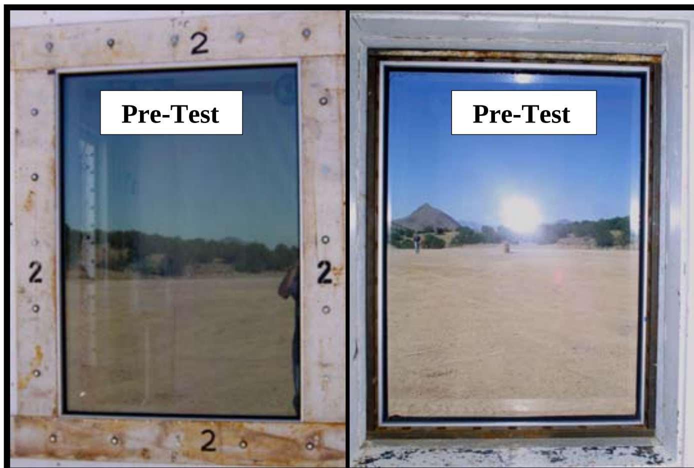




Test Structure 1, 3M Corporation Test 1
4.88 psi – 37.45 psi – msec

- S50NEAR400 Ultraflex.
- 1/4” monolithic annealed glass, 4-sided Wet glazed attachment.
- Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.
- Glazing cracked, pulled out of frame, and landed 119” outside of structure. No visible damage to frame.

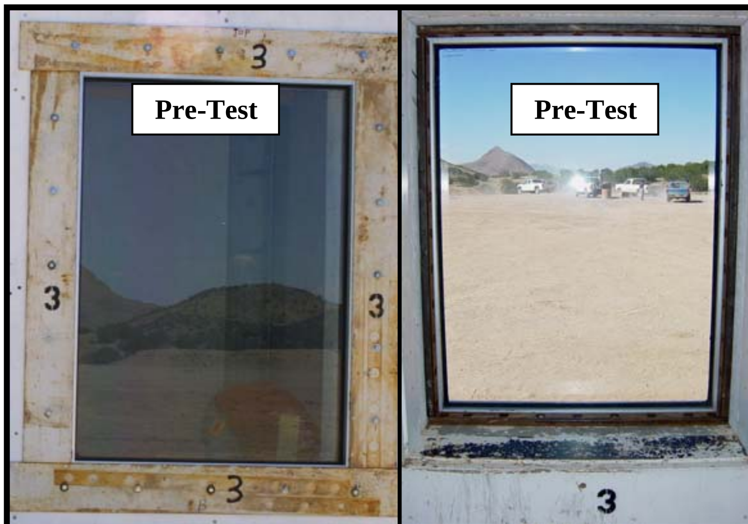
Figure E.2. Photographs and results of Test Structure 1, Test 1.



Test Structure 2, 3M Corporation Test 1
4.88 psi – 37.45 psi –msec

- S50NEAR400 Ultraflex.
- 1/4” monolithic annealed glass, 4-sided wet glazed attachment.
- Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.
- 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).

Figure E.3. Photographs and results of Test Structure 2, Test 1.



Test Structure 3, 3M Corporation Test 1
4.88 psi – 37.45psi – msec

- SCLARL400 Ultraflex.
- 1/4” monolithic annealed glass, 4-sided wet glazed attachment.
- Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.
- 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).

Figure E.4. Photographs and results of Test Structure 3, Test 1.

Test Structure 4, 3M Corporation Test 1
4.88 psi – 37.45 psi – msec

- SCLARL400 Ultraflex.
- 1/4” monolithic annealed glass, 4-sided wet glazed attachment.
- Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.
- 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).

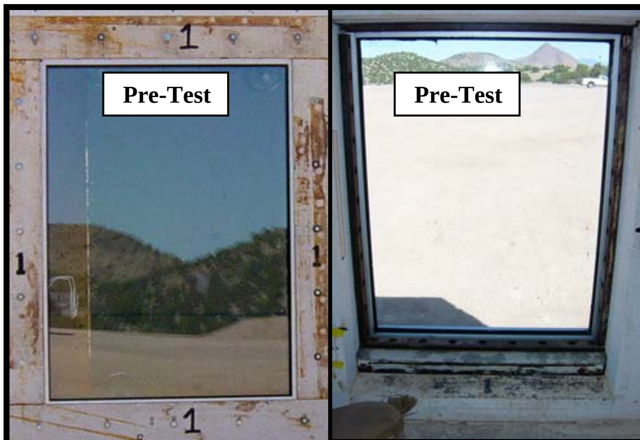
Figure E.5. Photographs and results of Test Structure 4, Test 1.

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.



Test Structure 1, 3M Corporation Test 2
5.00 psi – 37.38 psi – msec

- IGU: 1/4” monolithic AG (inner & outer panes), ½” air gap 4-sided wet-glazed attachment (Ultraflex), Ultra600 film with vertical butt-splice down center of pane.
- 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.
- 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

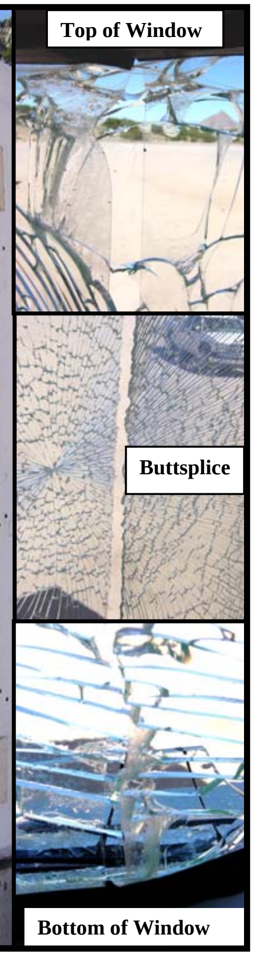


Figure E.6. Photographs and results of Test Structure 1, Test 2.

Test Structure 2, 3M Corporation Test 2
5.00 psi – 37.38 psi – msec

- 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.
- Large quantities of glass fell both inside and outside of test structure. Glass fragments landed in 3a – 3b region inside of test structure. Impacts on witness panel appeared to be caused by a piece of window frame that entered test structure. The dry glazing attached to the frame also looks to have caused a very small secondary impact and black discoloration on the witness panel.
- 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.

Figure E.7. Photographs and results of Test Structure 2, Test 2.

Test Structure 3, 3M Corporation Test 2
5.00 psi – 37.38 psi – msec

- 1/4” monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SCLARL400 film (with deflection indicator dots).
- Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on 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.

Figure E.8. Photographs and results of Test Structure 3, Test 2.

Test Structure 4, 3M Corporation Test 2
5.00 psi – 37.38 psi – msec

- 1/4” monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SH8+RE35NEARL film.
- Light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.
- Glazing cracked, pulled out of frame, and landed 145” outside of test structure. No visible damage to frame.

Figure E.9. Photographs and results of Test Structure 4, Test 2.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

When an explosion is detonated in an urban environment, window breakage is typically widespread and can occur over several city blocks. The window glass fragments generated by such an event are either driven into the buildings or drawn outside the buildings resulting in injury to building occupants and people on the street. For example, over 500 people in Oklahoma City sustained injuries (many due to window glass failure) and required medical attention due to the bombing of the A.P. Murrah Building in 1995. To reduce the window glass fragment hazards generated by blast, several technologies have emerged, including security window films, laminated glass, blast curtains, blast louvers, and new energy absorbing technologies.

The US General Services Administration (GSA) oversees design and construction of new facilities and manages the existing real property inventory for a large portion of the US Government. After the Oklahoma City bombing, the President issued a directive for government agencies to take action toward protecting government facilities. In response to this presidential directive, the GSA published a security criteria document (GSA Security Criteria, October 8, 1997), which specifically addresses blast protection issues for both new and existing GSA facilities. The criteria were followed by the Interagency Security Committee (ISC) Security Criteria, which was signed and officially adopted on May 28, 2001. That document was updated on October 31, 2003. Part of the ISC Security Criteria addresses window glazing and the associated hazard generated by blast. This portion of the criteria was based in part on a series of blast tests on windows performed by the GSA and other blast test data. The glazing criteria are performance based. The glass fragment hazard generated by windows is graded based on the post-blast location of glass fragments in a blast test. The GSA has indicated that manufacturers of glass fragment mitigating products must test their products to be considered for use in ISC Medium and Higher (GSA Level C and D) facilities.

3M Corporation commissioned ARA to perform two high-explosive blast tests to evaluate the performance of their window systems. The test data collected in this effort will provide useful information for many government and civilian entities that are responsible for security planning of building facilities.

The explosive tests were conducted at the Energetic Materials Research and Testing Center (EMRTC) in Socorro, New Mexico on September 16-17, 2004. The test procedure was designed in accordance with the procedure adopted by the GSA. The GSA test procedure (GSA-TS01-2003) is included in Appendix A. Both tests used 600 lb of ANFO, which is equivalent to 500 lb of TNT. The overall size of the window systems in Test Structures 1 through 4 were approximately 4 ft by 5-1/2 ft. The window systems were mounted in enclosed concrete reaction structures and metal plates were mounted around the framing of the window. The metal plates were attachment to the structures using 1-inch long #10 self-tapping screws spaced at 12 inches on center. The tests were conducted using a standoff distance to the charge of 165 ft for Test Structures 1 and 4.

1.2 OBJECTIVES

The primary objective of this test series was to evaluate the performance of 3M Corporation’s window systems subjected to a blast environment. The windows were evaluated per the US General Services Administration Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings, which is included in Appendix A.

1.3 ISC CRITERIA

The ISC Security Criteria glass fragment hazard rating scheme is presented graphically in Figure 1.1 and described in Table 1.1. The approach compares potential hazards based on the location of glass fragments interior and exterior to the test cubicle. These criteria indirectly reflect the velocity of fragments based on their distance from the original window position.

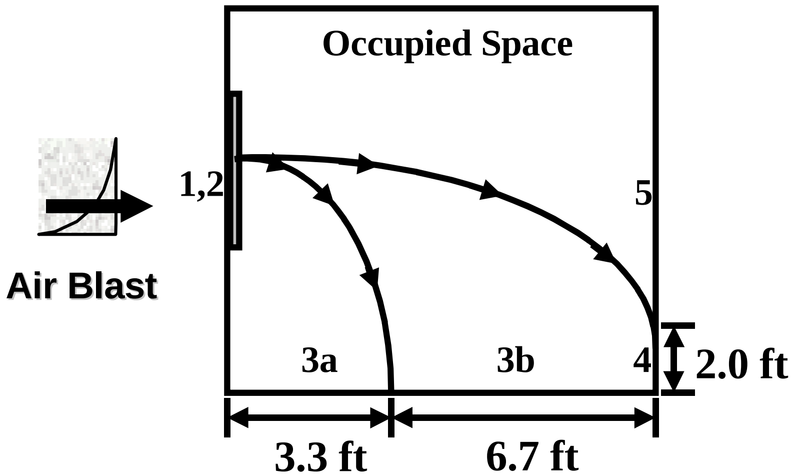


Figure 1.1. Glazing protection levels based on fragment impact locations.

Table 1.1. 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.

CHAPTER 2
TEST CONFIGURATION

2.1 TEST RANGE

The test series was performed at the Energetic Materials Research and Testing Center (EMRTC) located in Socorro, New Mexico. The test site is jointly operated by the New Mexico Institute of Mining and Technology and Applied Research Associates, Inc.

2.2 TEST STRUCTURES AND TEST BED

Three concrete reaction structures were used for this test, with one of the structures housing 2 windows. The test structures are shown in Figure 2.1. The reaction structures were enclosed and sealed to prevent airblast engulfment effects that occur in open frame blast tests. When a window or other specimen is blast tested in an open frame, the airblast engulfs the specimen before it can completely respond. The result is an airblast loading from both the front and the back of the window. The net load driving the specimen is the difference between the load on the front of the specimen and the back of the specimen. This net differential load is much less than that which is obtained by using an enclosed reaction structure. To best simulate the loads that can be expected on typical buildings, the enclosed reaction structure is required.

The charge standoff to the structures was 165 ft for Test Structures 1 through 4 for both tests. The nominal pressure reading for both tests can be seen in Table 2.1 below. Figure 2.2 shows the placement of the structures in relation to the charge for the blast test.

Table 2.1. Nominal Pressure Reading for each Window

Test Structure Window	Test 1 Nominal Pressure Reading (psi)	Test 2 Nominal Pressure Reading (psi)
1	4.88	5.06
2	4.93	5.11
3	4.95	4.93
4	4.78	4.90
Average	4.88	5.00

Rocks are abundant in the soil at the test site. In order to minimize the potential for rock impact of the specimens, the explosive charge was placed over a pit backfilled with clean sand, and the test bed was graded and raked before the test.

The test structures are nominally 14 ft deep from the window opening to the rear of the structure. Wood framed walls were erected in the rear of the structure for mounting the rigid foam witness panels. These witness panels were located approximately 120 inches from the back of the windows in accordance with the GSA test method (criteria dictates $\leq$10 ft). The witness panels were nominally 16 ft wide by 10 ft high and were located behind the window opening. Butcher paper was attached to the rigid foam covering the front of the witness panel and was examined after testing to determine if glass fragment impacts occurred.

2.3 INSTRUMENTATION

The test structures were instrumented with exterior pressure gauges, as shown in Figure 2.3. These gauges were used to monitor the reflected pressure near the window specimens. Two exterior pressure gauges were used for each test structure. Single gauges were located to the right and left of each window. Each gauge was mounted in the concrete wall near the center line of the window.

Interior pressure gauges were mounted inside each structure, as shown in Figure 2.3. These gauges were used to monitor the infill pressures for each window. Infill pressures from all tests were very small and would not likely pose a hazard to occupants. All measured pressure data is plotted in Appendix B along with a statistical summary for the test.

A high-speed film camera was located inside the structures, positioned on one side of the witness panel viewing the whole window. The camera utilized a Plexiglas screen to protect the lenses. All cameras were positioned on steel a tube stand that was rigidly mounted to the floor of the structure.

A high-speed film camera and a normal-speed video camera were located on an embankment to the northeast of the test bed to capture exterior views of the explosion and the structure. See Figure 2.4 for camera locations.

A weather station was used to monitor the ambient temperature, relative humidity, and barometric pressure for each test.

2.4 TEST CHARGE

The explosive charge used for the test was 600 lb of ammonium nitrate and fuel oil (ANFO) which is equivalent to 500 lb of TNT. The charge was built in a cardboard Sonotube with two detonators and three pentalite boosters (total weight 2 ¼ lb) located in the center of the charge. The ANFO charge was constructed as a 1:1 cylinder and was detonated at ground level. The charge standoff distance of 165 ft was confirmed with a measuring tape.

2.5 INSTALLATION DETAILS

All windows were tested in commercial aluminum frames. The frames were 2-inch by 4-1/2-inch storefront aluminum frames, with vision openings of nominally 46 inches by 64 inches. The aluminum frame windows had a ½-inch nominal bite. Windows were mounted by "sandwiching" the aluminum frames 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 ½-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. Frame details are shown in Appendix C.

The window systems containing wet-glazed attachments used 1/2 – inch (glazing edge) x 3/4 – inch (frame edge) silicone contact lengths. A sketch of the wet-glazed attachment is shown in Appendix C.

2.6 TEST MATRIX

A test matrix (Table 2.2) was designed by 3M Corporation in an attempt to get the most useful information from the number of specimens to be tested. All windows were tested in typical commercial aluminum frames. Glass configuration, glass type, film thickness and attachment were varied.

Table 2.2. Window layups for Test 1 and 2.

Standoff /Measured Peak Pressure	Window Number	Window Layups
Test 1 standoff = 165 ft Avg. pressure = 4.88 psi	1	1/4” monolithic AG, 4-sided wet-glazed attachment S50NEAR400 Ultraflex
	2	1/4” monolithic AG, 4-sided wet-glazed attachment S50NEAR400 Ultraflex
	3	1/4” monolithic AG, 4-sided wet-glazed attachment SCLARL400 Ultraflex
	4	1/4” monolithic AG, 4-sided wet-glazed attachment SCLARL400 Ultraflex
Test 2 standoff = 165 ft Avg. pressure = 5.00 psi	1	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.
	2	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.
	3	1/4” monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SCLARL400 film (with deflection indicator dots).
	4	1/4” monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SH8+RE35NEARL film

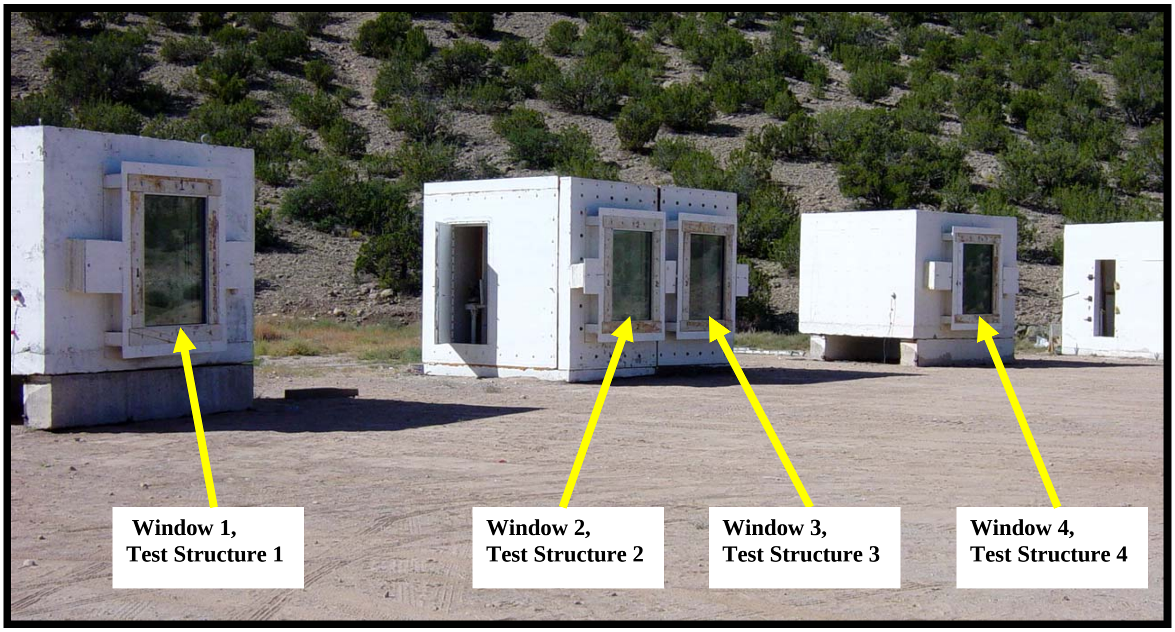


Figure 2.1. Test structures and window nomenclatures.

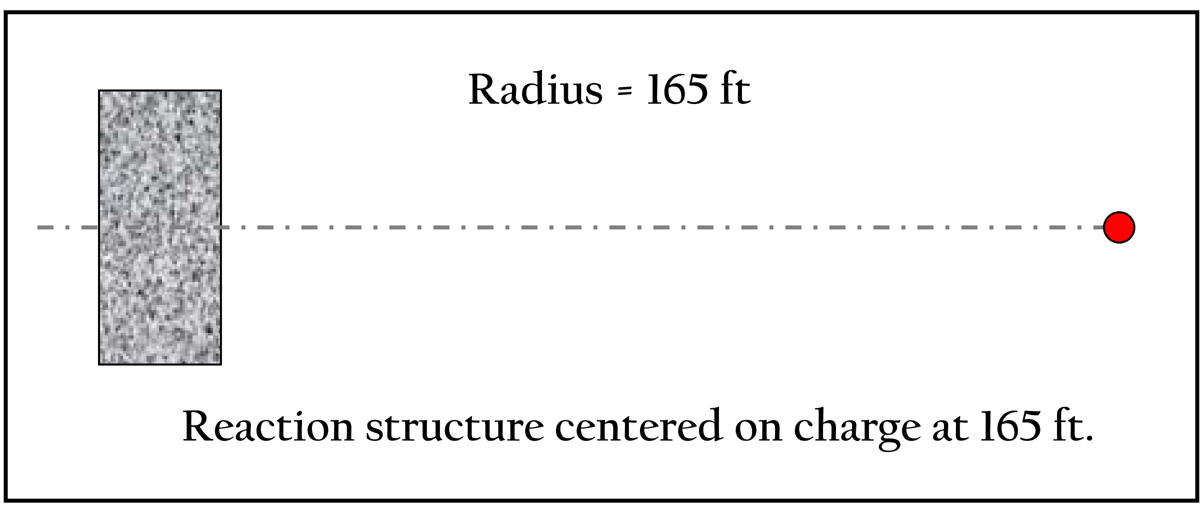


Figure 2.2. Orientation of Test Structures 1 through 4 (not drawn to scale).

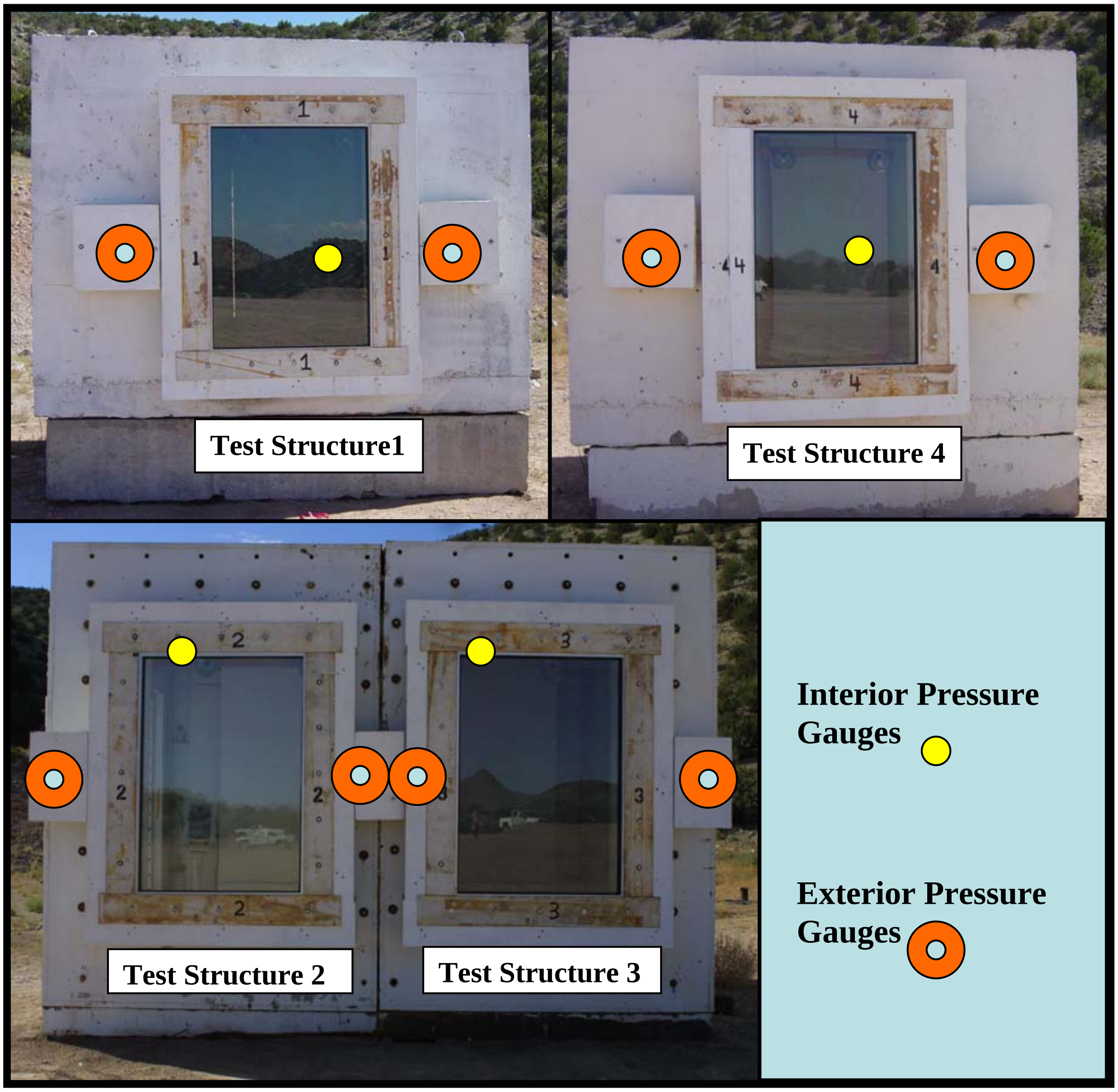


Figure 2.3. Exterior and interior pressure gauge locations.

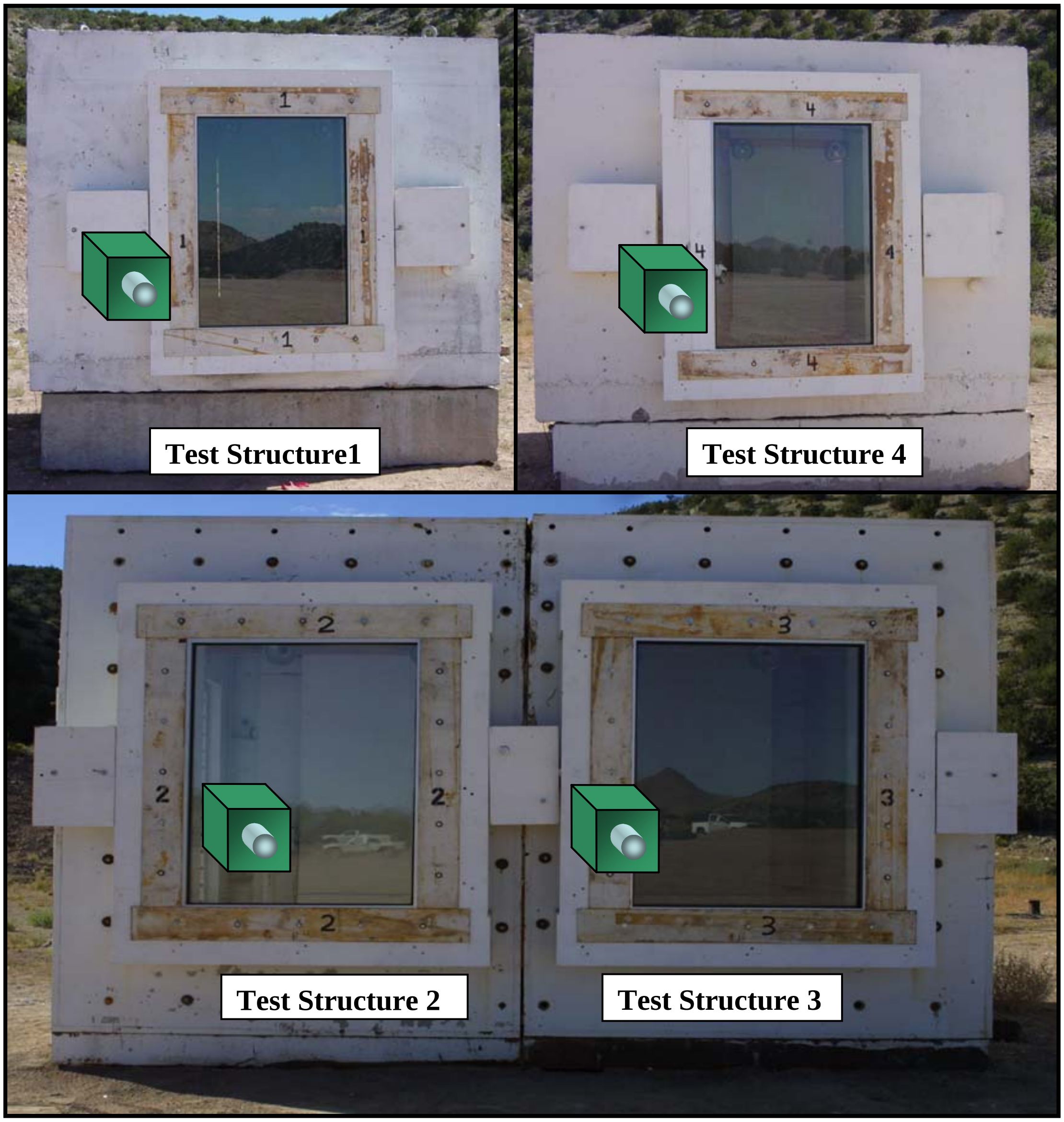


Figure 2.4. High speed camera locations.

CHAPTER 3
TEST RESULTS

3.1 TEST 1 RESULTS

The explosive charge used in Test 1 was detonated on September 16, 2004 at 4:16 pm. The charge was located at a standoff of 165 ft from the structure for a pre-test nominal target pressure of 4.90 psi. A typical airblast waveform is shown in Figure 3.1, and the average airblast values from the exterior gauges are given in Table 4.1. Statistical analysis was performed on the test data and is included in Appendix B.

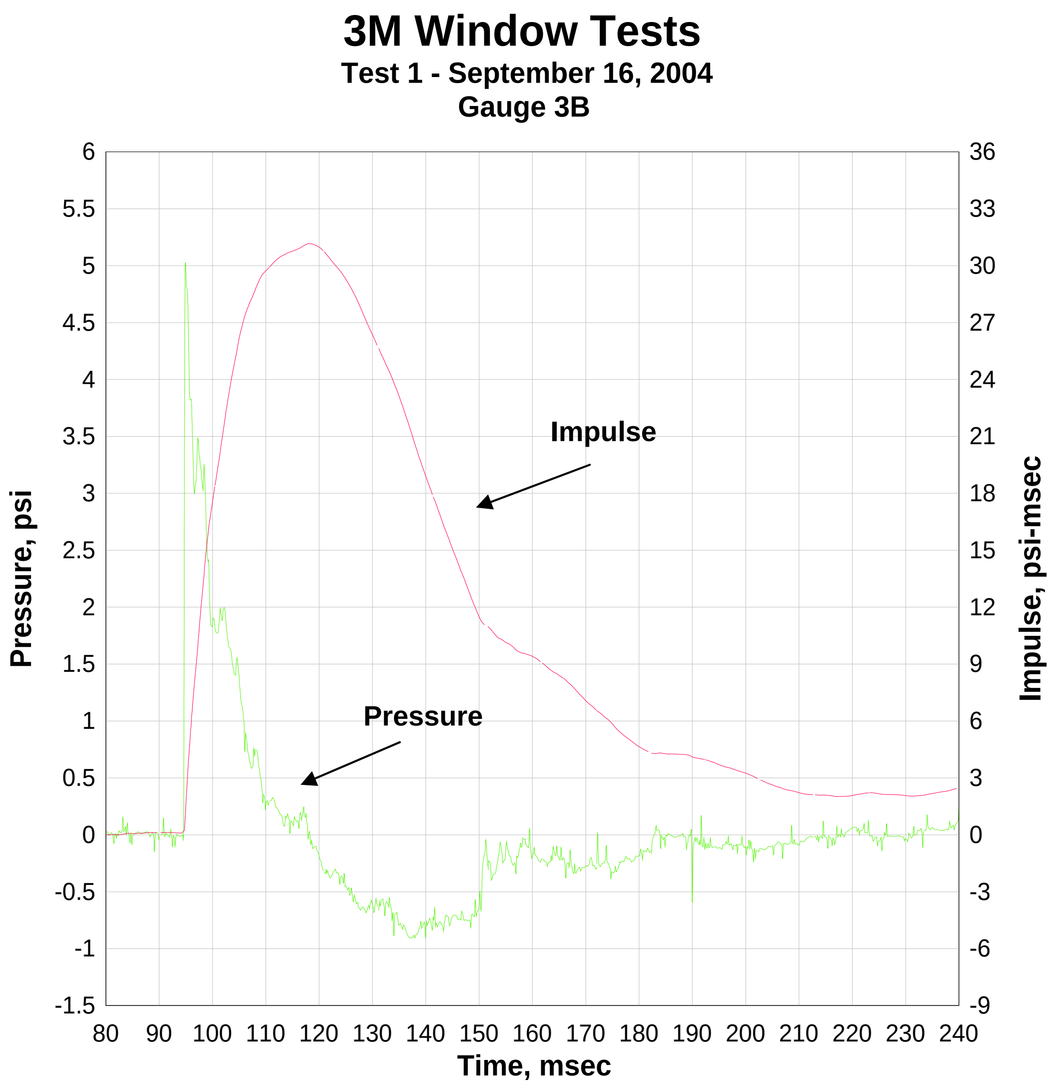


Figure 3-1 Typical airblast waveform Test 1.

Due to a pressure gauge malfunction, correct impulse values (i.e. pressure through time) were not obtained for several gauges during Test 1. Two of the gauges did, however, provide correct impulse values for this test. Peak pressure values obtained from all gauges during Test 1 were also correct. The gauge malfunction issue was corrected prior to performing Test 2.

3.1.1 Window 1

Description: 1/4" monolithic AG, 4-sided wet-glazed attachment S50NEAR400 Ultraflex
Rating: GSA Condition 3b

Glazing cracked, pulled out of frame, and landed 119" outside of structure. No visible damage to frame. There was also a light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.

A pre-test photo of the window is shown in Figure 3.2 and post test photos are shown in Figure 3.3 and Figure 3.4.

3.1.2 Window 2

Description: 1/4" monolithic AG, 4-sided wet-glazed attachment S50NEAR400 Ultraflex
Rating: GSA Condition 3b

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). There was also a light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.

A pre-test photo of the window is shown in Figure 3.5 and post test photos are in Figure 3.6 and Figure 3.7.

3.1.3 Window 3

Description: 1/4" monolithic AG, 4-sided wet-glazed attachment SCLARL400 Ultraflex
Rating: GSA Condition 3b

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). There was also a light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.

A pre-test photo of the window is shown in Figure 3.8 and post test photos are in Figure 3.9 and Figure 3.10.

3.1.4 Window 4

Description: 1/4" monolithic AG, 4-sided wet-glazed attachment SCLARL400 Ultraflex
Rating: GSA Condition 3b

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). There was also a light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.

A pre-test photo of the window is shown in Figure 3.11 and post test photos are in Figure 3.12 and Figure 3.13.

Figure 3.2. Exterior pre-test view of Window 1.

Figure 3.3. Exterior post-test view Window1.

Figure 3.4. Interior post-test view of Window 1.

Figure 3.5. Exterior pre-test view of Window 2.

Figure 3.6. Exterior post-test view of Window 2.

Figure 3.7. Exterior post-test view of Window 2.

Figure 3.8. Exterior pre-test view of Window 3.

Figure 3.9. Interior post-test view of Window 3.


Figure 3.10. Exterior post-test view of Window 3.

Figure 3.11. Exterior pre-test view of Window 4.

Figure 3.12. Interior post-test view of Window 4.

Figure 3.13. Exterior post-test view of Window 4.

3.2 TEST 2 RESULTS

The explosive charge in Test 2 was detonated on September 17, 2004 at 4:16 pm. The charge was located at a standoff of 165 ft from the structure for a pre-test nominal target pressure of 4.90 psi. A typical airblast waveform is shown in Figure 3.14, and the average airblast values from the exterior gages are given in Table 4.2. Statistical analysis was performed on the test data and is included in Appendix B.

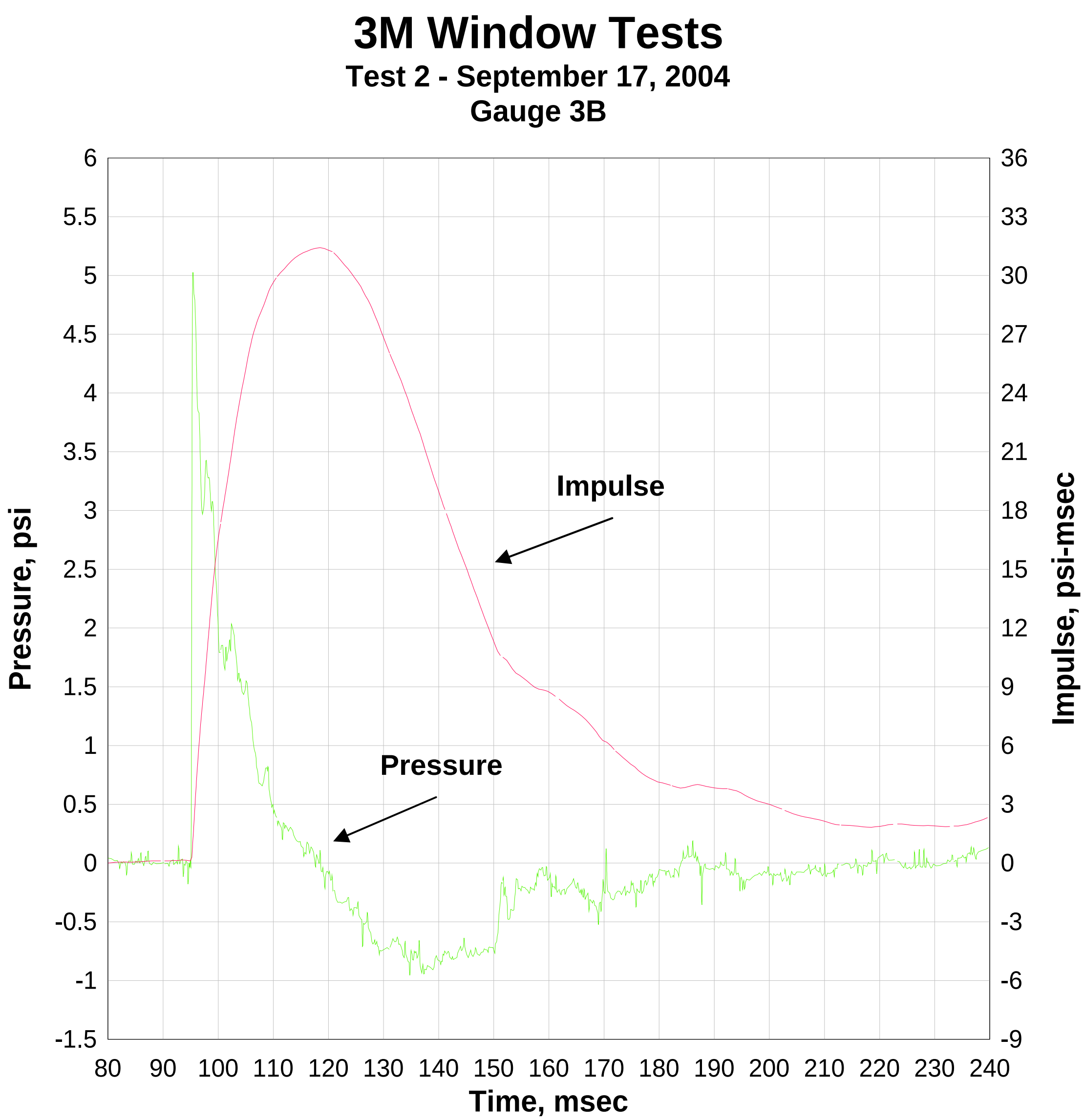


Figure 3.14. Typical airblast waveform Test 2.

3.2.1 Window 1

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.

Rating: GSA Condition 3b

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. Large glass fragments landed outside of structure and light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.

A pre-test photo of the window is shown in Figure 3.15 and post test photos are shown in Figure 3.16 and Figure 3.17.

3.2.2 Window 2

Description: 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.

Rating: GSA Condition 3b

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. The dry glazing attached to the frame also looks to have caused a very small secondary impact and black discoloration on the 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.

A pre-test photo of the window is shown in Figure 3.18 and post test photos are shown in Figure 3.19 and Figure 3.20.

3.2.3 Window 3

Description: 1/4” monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SCLARL400 film (with deflection indicator dots).

Rating: GSA Condition 3b

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. There was also a light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel.

A pre-test photo of the window is shown in Figure 3.21 and post test photos are shown in Figure 3.22 and Figure 3.23.

3.2.4 Window 4

Description: 1/4” monolithic AG, 4-sided wet-glazed attachment (Ultraflex), SH8+RE35NEARL film

Rating: GSA Condition 3b

Glazing cracked, pulled out of frame, and landed 145” outside of test structure. No visible damage to frame. There was also a light dusting of glass inside of test structure with larger fragments landing in 3a – 3b region. No impacts evident on witness panel

A pre-test photo of the window is shown in Figure 3-24 and post test photos are shown in Figure 3-25 and Figure 3-26.

Figure 3.15. Exterior pre-test view of Window 1.

Figure 3.16. Interior post-test view of Window 1.

Figure 3.17. Exterior post-test view of Window 1.

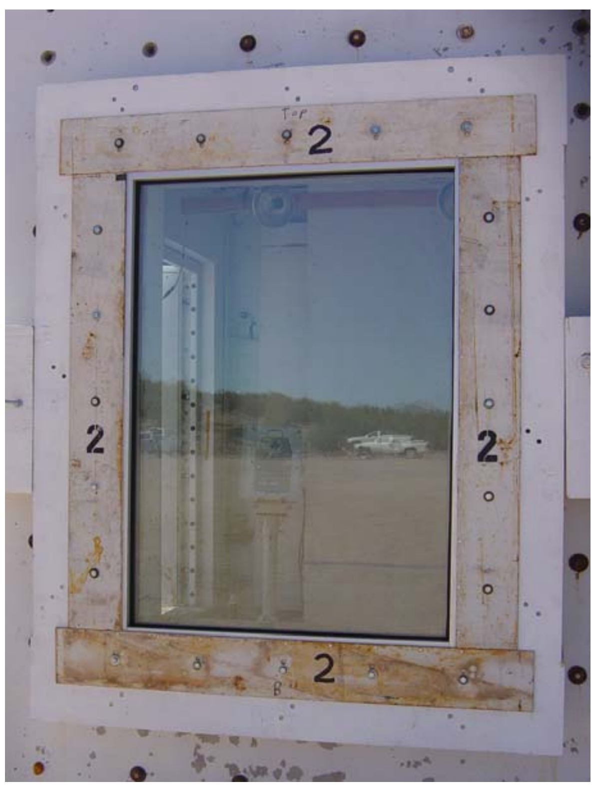


Figure 3.18. Exterior pre-test view of Window 2.

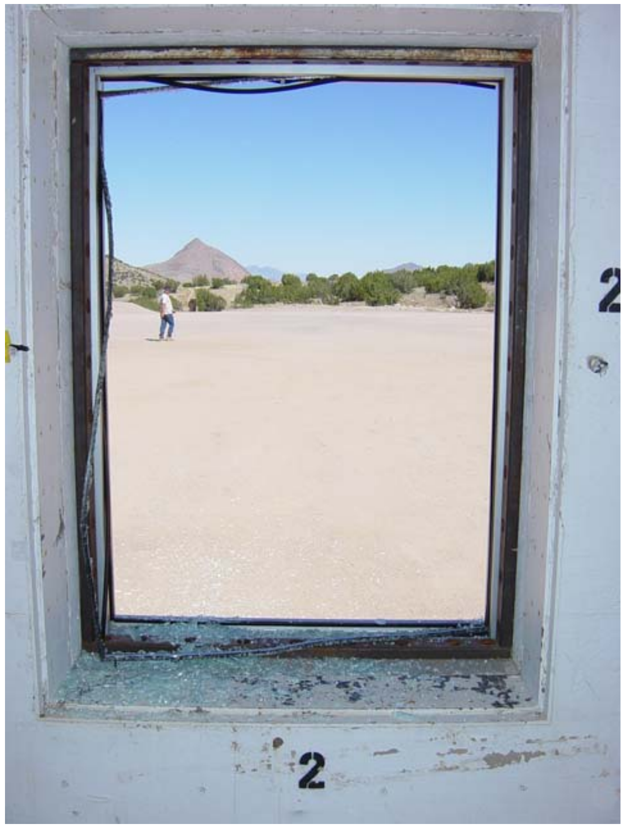


Figure 3.19. Interior post-test view of Window 2.

Figure 3.20. Exterior post-test view of Window 2.

Figure 3.21. Exterior pre-test view of Window 3.

Figure 3.22. Interior post-test view of Window 3.

Figure 3.23. Exterior post-test view of Window 3.

Figure 3.24. Exterior pre-test view of Window 4.

Figure 3.25. Exterior post-test view of Window 4.

Figure 3.26. Exterior post-test view of Window 4.

CHAPTER 4
RESULTS SUMMARIES AND MAJOR FINDINGS

4.1 IMPLICATION OF RESULTS AND GSA SECURITY REQUIREMENTS

The ISC (GSA) Security Criteria for window response requires that windows meet a certain level of performance for a particular design threat. This is true for GSA buildings with ISC protection levels of Medium and Higher (GSA Levels C and D). Buildings at the Low and Medium/Low levels of protection, which are lower in security classification than the Medium and Higher buildings, require no specific performance criteria, though use of certain window types is discouraged.

Government agencies outside of the GSA may require reporting of fragment weight distribution within the test structure. The post-test weight distribution of glass fragments inside of the structure for each window tested is included in Appendix D.

For ISC Medium (GSA Level C) buildings, the typical design blast load is a triangular pulse that instantaneously rises to 4 psi and decays linearly to zero over a duration of 13.9 milliseconds (msec). The impulse that the specified design blast load generates is 28 psi-msec. The performance required for ISC Medium (GSA Level C) buildings is a condition 4 or lower. The average impulses generated during the testing ranged from 37.38 to 37.45 psi-msec with an average peak pressure of 4.88 to 5.00 psi. Thus, window specimens that performed to a condition 4 or better from this test series can be considered for use in ISC Medium (GSA Level C) buildings. Only window systems of the tested size and smaller in a similar configuration (framing and support conditions) can be directly compared to the test data from this test series. Other configurations must be designed by a qualified blast consultant for the specific application.

4.2 CONSOLIDATED RESULTS

The results of the test are consolidated into the tables below.

Table 4.1 Summary of results for Test 1.

Summary				
Test Article	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
Pressure (psi)	4.88	4.88	4.88	4.88
Impulse (psi-msec)	37.45	37.45	37.45	37.45
GSA Performance Condition	3b	3b	3b	3b

Table 4.2 Summary of results for Test 2.

Summary				
Test Article	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
Pressure (psi)	5.00	5.00	5.00	5.00
Impulse (psi-msec)	37.38	37.38	37.38	37.38
GSA Performance Condition	3b	3b	3b	3b

APPENDIX A

GSA TEST METHOD

US General Services Administration Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings

1. Introduction

This test standard is intended to ensure an adequate measure of standardization and quality assurance in the testing of window systems including but not limited to glazing, sealants, seats and seals, frames, anchorages and all attachments and/or secondary catcher or restraint mechanisms designed to mitigate the hazards from flying glass and debris. This standard is the sole test protocol by which blast resistant windows and related hazard mitigation technology and products shall be evaluated for facilities under the control and responsibility of the US General Services Administration (GSA).[1]

2. Standard Designation

GSA Test Protocol: GSA-TS01-2003
Issue Date: January 1, 2003
Distribution: There are no publication or distribution restrictions for this standard.

3. References

a. "GSA Security Criteria, Final Working Version", Building Technologies Division, Office of Property Development, Public Buildings Service, General Services Administration, October 8, 1997, For Official Use Only.

b. "ISC Security Design Criteria for New Federal Office Buildings and Major Renovation Projects", The Interagency Security Committee (ISC), May 28, 2001, For Official Use Only.

4. Terms and Definitions

The following terms and definitions are provided to facilitate the implementation of this test standard.

ANFO – A mixture of Ammonium Nitrate and Fuel Oil designed to produce explosive effects.

Annealed Glass (AG) – This is the most common glass type that is used in construction. It is also the weakest glass type and fails in large hazardous dagger-like fragments.

Bite – The depth of glass or glazing that is captured in the window frame.

Explosive – Any substance or device, which will produce upon release of its potential energy, a sudden outburst of energy thereby exerting high pressures on its surroundings.

Fully Thermally Tempered Glass (TTG) – This glass type has about four times the compressive strength of regular annealed glass. TTG is the same glass used by car manufacturers for side windows in automobiles. It is often called safety glass. The fully thermally tempered glass tends to dice into small cube like pieces upon failure.

GSA Building Security Technology Program – GSA's Office of the Chief Architect has conducted research and developed technology in order to produce the tools and methodologies required to implement blast hazard mitigation in open, public facilities. The technology transfer web site www.oca.gsa.gov presents the major products and findings of this program.

[1] Tests performed prior to January 1, 2003 that used the previous GSA test protocol, "US General Services Administration (GSA) Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings," shall be accepted as having fully complied with all requirements of this standard.

Heat Strengthened Glass (HSG) – This glass type is partially tempered. It has approximately twice the compressive strength of typical annealed glass. Like AG, HSG fails in large, dangerous shards.

Incident Pressure – The overpressure (i.e., pressure above ambient) produced by an explosion in the absence of a structure or other object. Units are typically psi.

Impulse – The area under a pressure-time waveform. Units are typically psi-msec.

Interlayer – Any material used to bond two lites of glass and/or other glazing material together to form a laminate. For annealed glass the interlayer is normally a 0.030 in. thick polyvinyl butyral (PVB). For thermally tempered glass the interlayer is normally a 0.060 in. thick PVB. Some applications use a thicker interlayer (0.090 in. and 0.120 in. are sometimes used in special applications).

Laminated Glass – Two or more plies of glass bonded together by interlayer(s). When broken, the interlayer tends to retain the glass fragments.

Lexan – Lexan® is GE's product name for polycarbonate.

Lite – Another term for a pane of glass.

mil – Unit of measure commonly used for reporting laminate interlayer or security window film thickness. 1 mil = 1/1000th of 1 inch.

Monolithic Glass – A single sheet of glass without any laminations.

Plastic Explosive – Any of a series of plastic demolition explosives with great shattering power. These normally typically contain a high percentage of a high explosive such as RDX combined with a mixture of various oils, waxes, and plasticizers. Upon manipulation these materials consolidate into a rubbery fully plasticized mass that may be kneaded and pressed into any shape. Plastic explosives have excellent mechanical and adhesive properties, and may be stretched into long strands without breakage.

Polycarbonate – Any of a family of thermoplastics marked by a high softening temperature and high impact strength. Polycarbonate is extensively used in ballistic resistant window applications.

Primary Fragments – Fragments produced directly from the contents or casing of an explosive device.

Quasi-static Pressure – The late-time pressure produced in an internal detonation. It consists of slowly decaying shocks as well as gas pressures. The duration of the quasi-static pressure depends upon the vented area relative to the volume of the space affected. Units are typically psi.

Reflected Pressure – Pressure pulse generated when a shock front impinges onto an unyielding surface. Units are typically psi.

SDOF – Single-degree-of-freedom (SDOF) systems are commonly used for the analysis of windows under blast-induced loads. Using this approach for dynamic analysis, a given structure or window component is reduced to an "equivalent" SDOF system and its dynamic deflections can be determined. Deflections determined from the SDOF system will be equivalent to the deflection of a specified point in the real structure or structural element. With the deflections known, basic structural analysis principles can then be used to proceed with the analysis and/or design. More sophisticated methods such as multi-degree-of-freedom (MDOF) or finite element methods may be required or preferred in some cases.

Setback – The distance between where a bomb is allowed and the target.

Secondary Fragments – Fragments produced by an explosive device that are made up of the target materials or other materials other than those directly resulting from the device itself.

Security Window Film – A thin material, usually a polyester composite, that is applied to a glass surface for the purpose of controlling failure. Security window film, in the context of mitigating hazards from blast, is normally 7-mil (7/1000 in.) thick or thicker. Some manufacturers have special multi-layered products in the 4-mil thickness range that possess properties approaching that of normal 7-mil products. These films are normally applied to the interior surface of the glass. Security window film may be optically clear, tinted, or reflective. They may be daylight, edge-to-edge, wet glazed or mechanically attached to the window frame. Mechanical attachment normally provides the higher levels of protection.

Shock Front – A shock wave is a wave formed of a zone of extremely high pressure within a fluid, especially one such as the atmosphere that propagates through the fluid at supersonic speed, i.e., faster than the speed of sound. Shock waves are caused by the sudden, violent disturbance of a fluid, such as that created by a powerful explosion or by the supersonic flow of a fluid over a solid object. The rapid expansion of hot gases resulting from detonation of an explosive charge will form a shock wave. The leading edge of the shock wave is commonly referred to as the shock front.

Standoff – Standoff is synonymous with setback and may be used interchangeably with the term setback.

Thermally Tempered Glass – See Fully Thermally Tempered Glass.

TNT – Trinitrotoluene (TNT), a pale yellow, solid organic nitrogen compound used chiefly as an explosive, prepared by stepwise nitration of toluene. Because TNT melts at 82º C (178º F) and does not explode below 240º C (464º F), it can be melted in steam-heated vessels and poured into casings. It is relatively insensitive to shock and cannot be exploded without a detonator. For these reasons, it is one of the most favored chemical explosives and is extensively used in munitions and for demolitions.

WINGARD – WINdow Glazing Analysis Response and Design is a computer program available from the US General Services Administration (www.oca.gsa.gov). This program is the GSA and ISC standard for the analysis and design of windows subjected to blast loads.

WINLAC – WINdow Lite Analysis Code is a computer program available from the US Department of State. Versions 4.0 and later are derivative versions of the GSA code ***WINGARD*** adapted to meet the unique requirements of the US Department of State.

5. Performance Criteria

This test method uses the ISC Security Design Criteria (Reference 3.b.) to rate the performance of window systems subjected to airblast loads. Protection and related hazard levels are categorized as a performance condition as indicated in Table 1 and Figure 1. These conditions are determined based upon the post-test location of fragments and debris relative to the original (pre-test) location of the window. Predictions of glazing response should be conducted with the computer program ***WINGARD***. The computer program ***WINLAC*** may be used for projects or tests supporting the US Department of State.

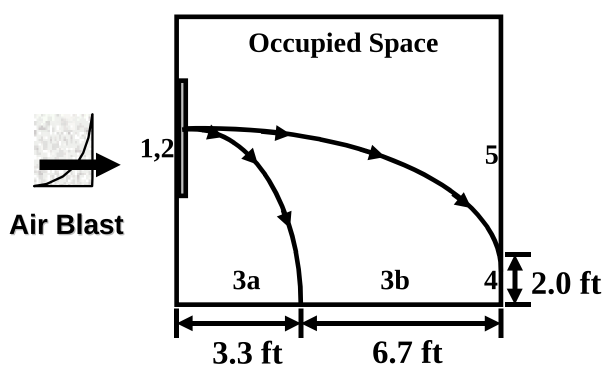


Figure A.1. GSA/ISC performance conditions for window system response.

Table A.1. GSA/ISC Performance Conditions for Window System Response.

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.

6. Requirements

6.1 Test Conductor

The test conductor shall be responsible for executing the test(s). The test conductor shall be an agency/organization that is qualified to perform such services and should be independent of the test specimen manufacturer or vendor.

6.2 Methods

Tests performed using this standard may be performed as open-air high explosives events or may use shock tubes to generate the required blast pressure loadings.

6.3 Blast Loads

In order to meet GSA requirements, tests meeting this standard shall produce a blast pressure pulse that rises instantaneously to a peak overpressure, P, and decays with time to produce a positive phase impulse, I. The actual measured values of P and I shall meet or exceed those required by relevant GSA project or test specifications in accordance with applicable security design criteria. The pressure-time waveform shall have one primary positive phase peak followed by a decay in pressure. Significant secondary pressure pulses should be avoided and under no circumstances shall significant secondary pressure pulses exceed a value of P/4, unless specifically required by the project specification or design criteria. A negative pressure phase is desired in order to replicate actual explosive loading conditions.

6.4 Test Site, Test Apparatus and Test Instrumentation

Tests performed under this standard may use explosive charges or shock tube. The test environment must produce the desired pressure and impulse as well as the desired pressure-time waveform characteristics. In general, explosive charges in open-air tests are preferred since they generally produce complete pressure waveforms that replicate the environments of interest.

6.4.1 Test Reaction Structures and Witness Panels and Test Framing

The test reaction structures shall be enclosed structures that prevent the rapid blast pressure engulfment of the test specimens. For tests that use open-air explosive charges, the test reaction structures shall be placed at appropriate distances and angles of incidence to produce the desired pressure-time loading conditions. The test reaction structures shall be non-responding relative to the test specimen(s) unless the response of the supporting reaction structure is important to demonstrating the performance of the tested specimen. If a responding support structure is required to demonstrate the performance of the specimen(s), then an appropriate responding structure should be provided. For tests using shock tubes, an enclosed reaction structure shall be provided at the end of the shock tube in a manner similar to that used for open-air explosive tests. This enclosed structure shall be designed to allow a failed window system to enter the enclosed space and land on the floor and/or impact the witness panel in order to allow determination of the performance condition as shown in Figure 1. An enclosed structure is also required so that infill pressures may be measured in the enclosed space after window failure.

A witness panel designed to record fragment and debris impacts shall be located within the enclosed reaction structure a distance not to exceed 10 ft from the interior face of the window glazing. The witness panel shall consist of a foam board with a thin aluminum sheet or paper to record penetrations and/or perforations.

Test specimens shall be mounted in frames that replicate the desired in-place conditions. For example, if the test is designed to demonstrate a system in a truly non-reacting frame then a frame shall be provided that offers sufficient resistance to load. Likewise, if a test is designed to demonstrate an energy absorbing system, then a suitable frame shall be provided.

6.4.2 Explosive Charges and Source
For tests using explosive charges, a high explosive source shall be used to generate the desired peak pressure and the positive phase impulse on the test specimen. Any type of explosive may be used as long as the desired waveform characteristics are produced and the tests are reproducible within acceptable ranges of P and I. The charge shall be hemispherical and detonated at ground level. Other charge configurations can be used. The effects of using other charge configurations must be accounted for and documented. If required to reduce the potential for ejecta debris from the crater, a blast mat, concrete pad or sand pit may be used at the discretion of the test conductor.

For tests using shock tubes, explosives or compressed gas with a rupture diaphragm may be used to generate the desired peak pressure and positive phase impulse on the test specimen. The test source must be designed so as not to overload the specimen with excess impulse. A negative pressure phase is desired in order to replicate actual explosive loading conditions.

6.4.3 Photographic Measurements
Photographic equipment shall be available to document the test. High-speed photography (500 to 1,000 frames per second), normal speed video, and still photography are recommended. As minimum, there should be at least one high-speed camera to record the response of each test specimen from an interior view. In addition, pre- and post-test still photography is required to document the condition of the tested specimens. Still photography shall be provided for both interior and exterior views.

6.4.4 Active Instrumentation and Data Acquisition
A minimum of two airblast pressure transducers shall be used on each test reaction structure to measure the pressure-time waveform acting on the exterior surface of tested specimens. A minimum of one interior pressure transducer is required in each test structure. If interior partitions are used to isolate interior pressure environments for the test specimens, an interior pressure transducer shall be used in each partitioned volume containing one or more test specimens. The airblast pressure transducers shall be capable of defining the anticipated airblast pressure-time history within the linear range of the transducer. The transducers shall have a rise/response time and resolution sufficient to capture the complete event.

Data Acquisition System (DAS)—The DAS shall consist of either an analog or digital recording system with a sufficient number of channels to accommodate the pressure transducers and any other electronic measuring devices.

6.5 Specimens
The test sponsor shall provide the test specimens. The test sponsor shall provide extra specimens in case of accidental breakage or damage during shipping. Each specimen shall be marked with the manufacturer's name, model and serial numbers (if applicable), and date of manufacture. In addition, each specimen shall be marked to indicate the proper orientation (i.e., interior/exterior) to ensure proper mounting in the test reaction structures. The specimens shall be mounted and anchored in the reaction structures in accordance with the manufacturer's instructions. The test conductor shall ensure that the test specimens are handled and stored in compliance with manufacturer's instructions.

Unless intended to replicate a specific condition or designed to meet specific project requirements, the standard test window size shall be nominally 48 inches wide by 66 inches tall. The window should be mounted in the test reaction structure such that the windowsill height replicates the desired in-place conditions for a particular project, or if performed as a generic test, should be approximately 24 inches off the reaction structure floor. Actual tested conditions shall be recorded and reported.

6.6 Test Measurements

6.6.1 Prior to the Test
Prior to the test, the test conductor shall:

- Record the ambient temperature within 30 minutes of test time.
- Measure and record test specimen dimensions. Measure and report actual glazing thickness.
- Photographically record the pre-test condition of the test specimens, the test frame, and the test site/apparatus configuration. This photographic record shall consist of still photographs and may include motion pictures or video.
- For tests using explosives, measure and record the test charge construction and the standoff distance from the center of the charge to the exterior face of the test specimen(s).
- For shock tube tests, measure and record the blast source construction (compressed gas and/or explosives).

6.6.2 After the Test
After the test, the test conductor shall:

- Photographically record the post-test condition of the test specimen(s), the location of any fragments/debris in the reaction structure, the test frame(s), and the test site/apparatus. This photographic record shall consist of still photographs and may include motion pictures or video.
- Record and photograph any perforations and/or penetrations of the witness panel.
- Determine and record the performance condition in accordance with the criteria shown in Table 1 and Figure 1. Minor dents or scratches on the witness panel paper or aluminum sheet that do not penetrate or perforate shall be noted but not counted as fragment/debris impacts for the purpose of determining the performance condition.

6.6.3 Units of Measure
The preferred units of measure for these tests are as follows:

- <u>Length, width, thickness, depth, displacement</u>: feet, inches, mil
- <u>Time</u>: sec, msec
- <u>Weight, force</u>: lb
- <u>Pressure</u>: lb/in^2 (psi)
- <u>Impulse</u>: psi-msec
- <u>Temperature</u>: deg F

6.7 Reports
Upon completion of a test, the test conductor shall report the results of the test. The following mandatory information shall be reported. Additional information may be reported as appropriate.

- Test site location, test date and time.
- Description of the test site or apparatus setup. This should include a description of the explosive charge and/or other explosive shock wave source used in the test.
- Pre- and post-test description of the test specimen(s), including pertinent dimensions, construction, materials and condition.
- Pre- and post-test description of the test framing and anchorage.
- Ambient temperature for each test.
- Peak positive pressure, P, and positive phase impulse, I, recorded by each pressure transducer. Average measured pressure and impulse. Descriptions of any anomalous measurements.
- The recorded airblast pressure-time history from each pressure transducer.
- The location of any debris and/or fragments to include any perforations and/or penetrations of the witness panel.
- The performance condition for each tested specimen in accordance with Table 1 and Figure 1.
- The test report shall contain a photographic record of the test setup. In addition, the test report shall contain detailed photographs of each test specimen prior to and following the test.

The test conductor shall keep an original of the test report on file for at least three years from submittal of the test report to the test sponsor. The test conductor shall provide a minimum of one copy of the test report plus applicable video and photographic records to the test sponsor.

APPENDIX B

MEASURED PRESSURE DATA

Pressure gauges were installed in the reaction structure to measure the pressure levels that the window systems experienced in the explosive test. There were a total of 12 gauges used during this series. Figure B.1 shows the location of each gauge.

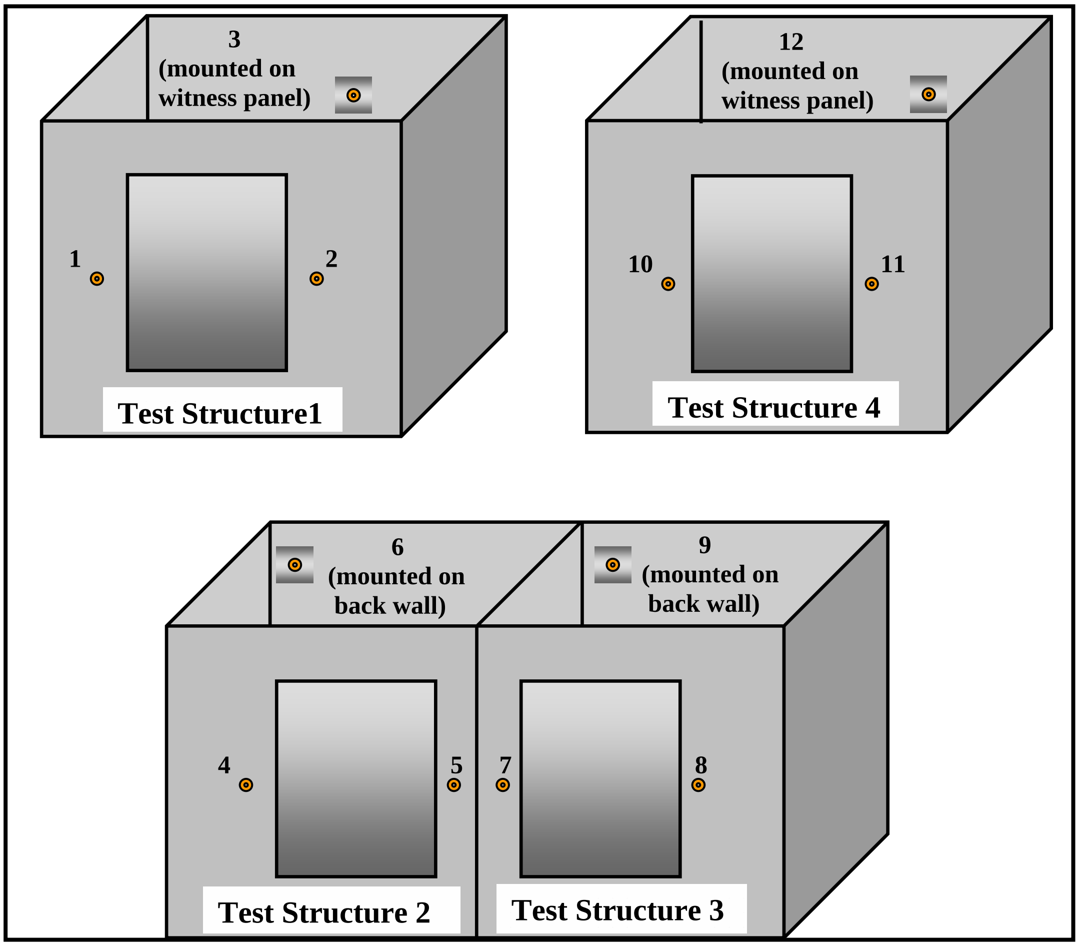


Figure B.1. Illustration of pressure gauge locations.

The table below (Table B.1) summarizes the peak measured pressures and impulses. Waveforms for each of the gauges follow the table. It should be noted that when attempting to determine the peak pressure and impulses, obvious noise (spikes) in the waveforms were ignored.

Table B.1. Summary of the peak pressures and impulses.

Note:Gauges with no values listed were not functioning correctly, and therefore, their output was not included in the results.

Test Number	Gauge Number */ Average/ Standard Deviation	Peak Positive Pressure (psi)	Peak Positive Impulse (psi-msec)
1	1a	4.77	----
	1b	4.99	----
	1c	0.37	10.90
	2a	5.08	----
	2b	4.77	43.73
	2c	0.20	2.13
	3a	4.86	----
	3b	5.03	31.17
	3c	0.24	6.78
	4a	4.76	----
	4b	4.80	----
	4c	0.26	6.85
	Average External Gauge	4.88	37.80
	Standard Deviation External Gauge	0.13	6.04
2	1a	5.05	30.83
	1b	5.06	----
	1c	0.38	9.53
	2a	5.22	34.37
	2b	5	40.57
	2c	0.17	1.1
	3a	4.83	36.48
	3b	5.03	31.43
	3c	0.22	7.39
	4a	4.87	44.55
	4b	4.92	43.45
	4c	0.25	7.01
	Average External Gauge	5.00	37.38
	Standard Deviation External Gauge	0.13	5.58

*Pressure Gauges 1a, 1b, 2a, 2b, 3a, 3b, 4a, and 4b are located on the exterior of the structures. Pressure gauges 1c, 2c, 3c, and 4c are located on the interior of the structures. For reference see FigureB.1.

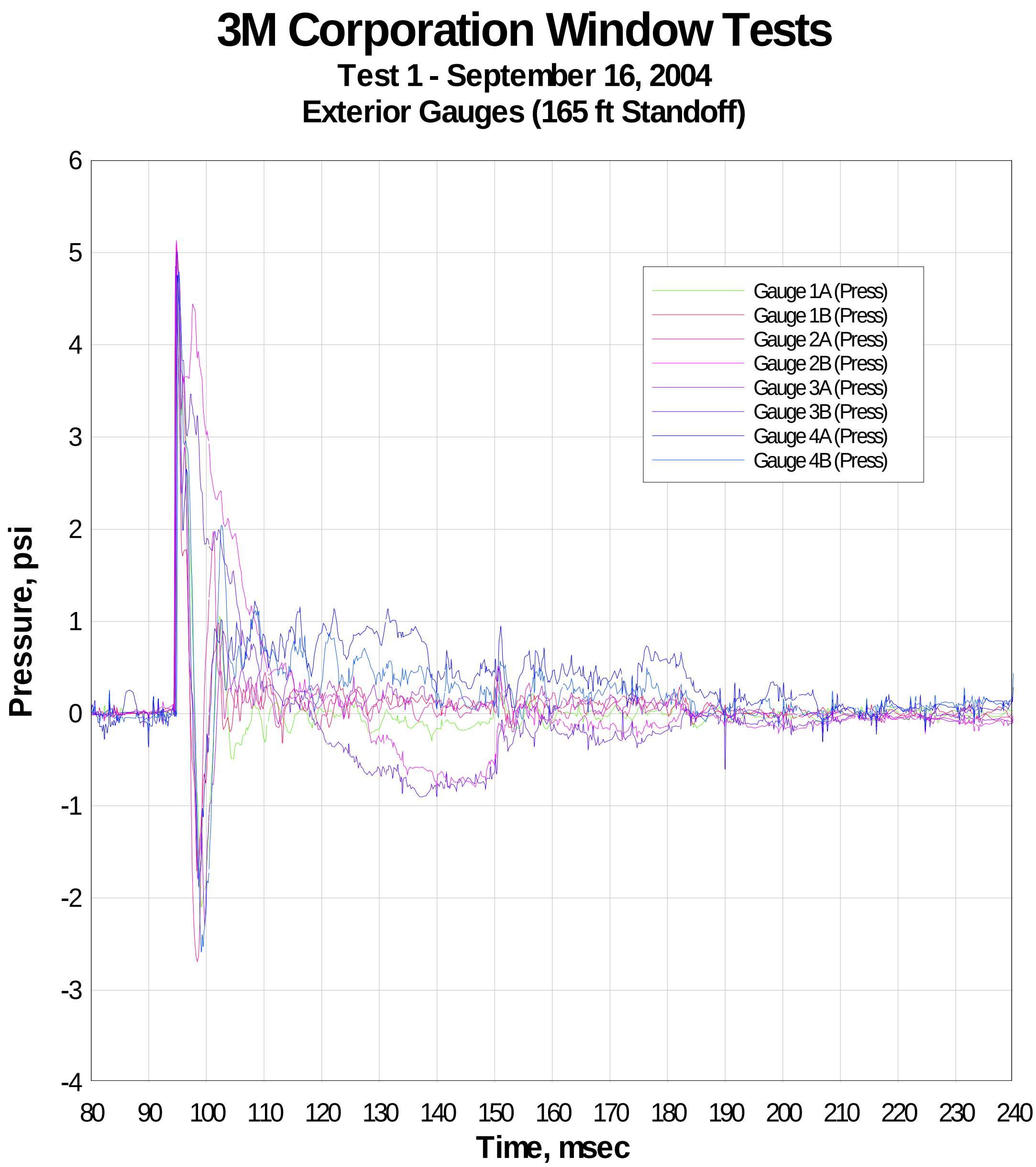


Figure B.1. Test 1, exterior gauge pressure.

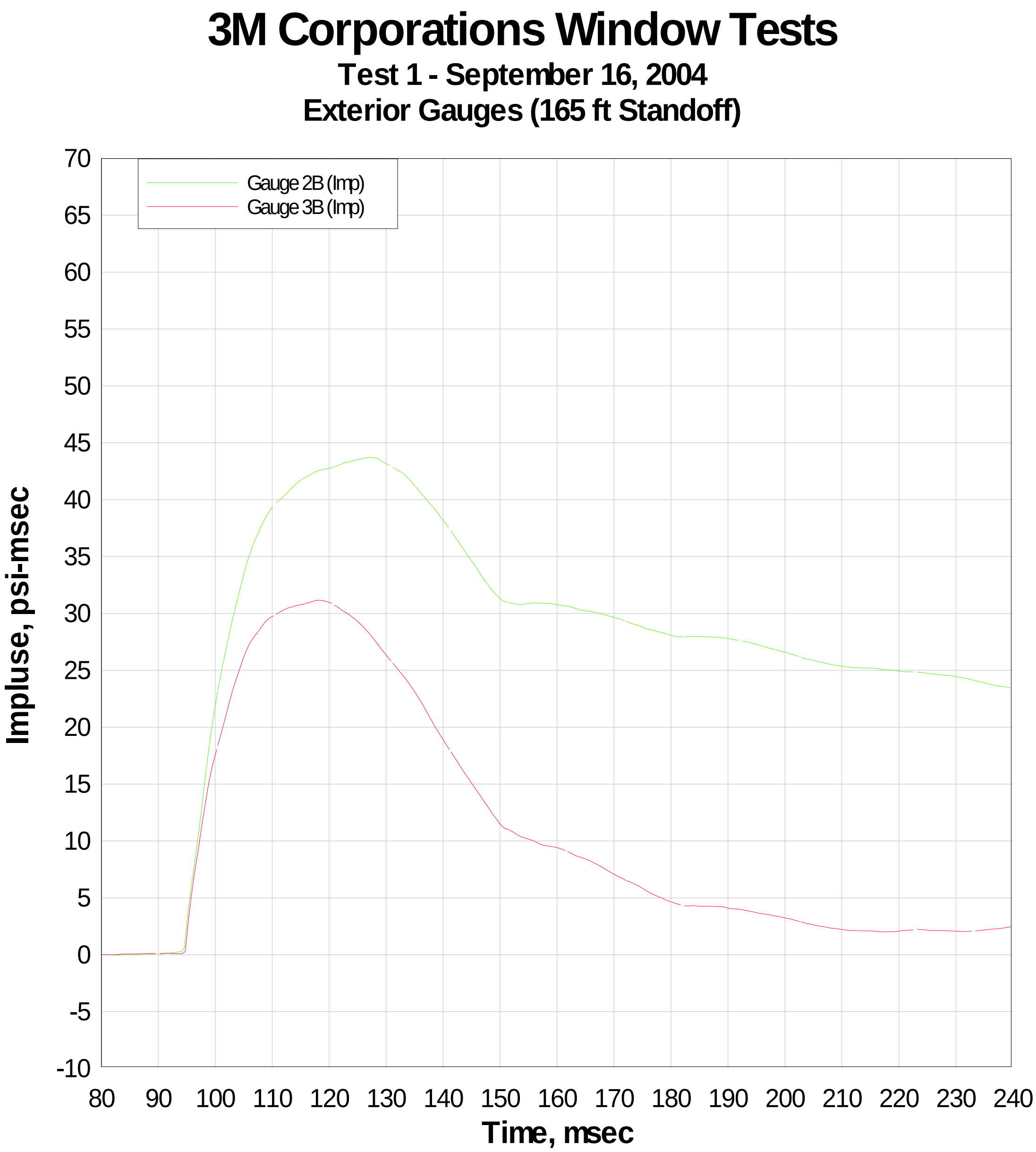


Figure B.2. Test 1, exterior gauge impulse.

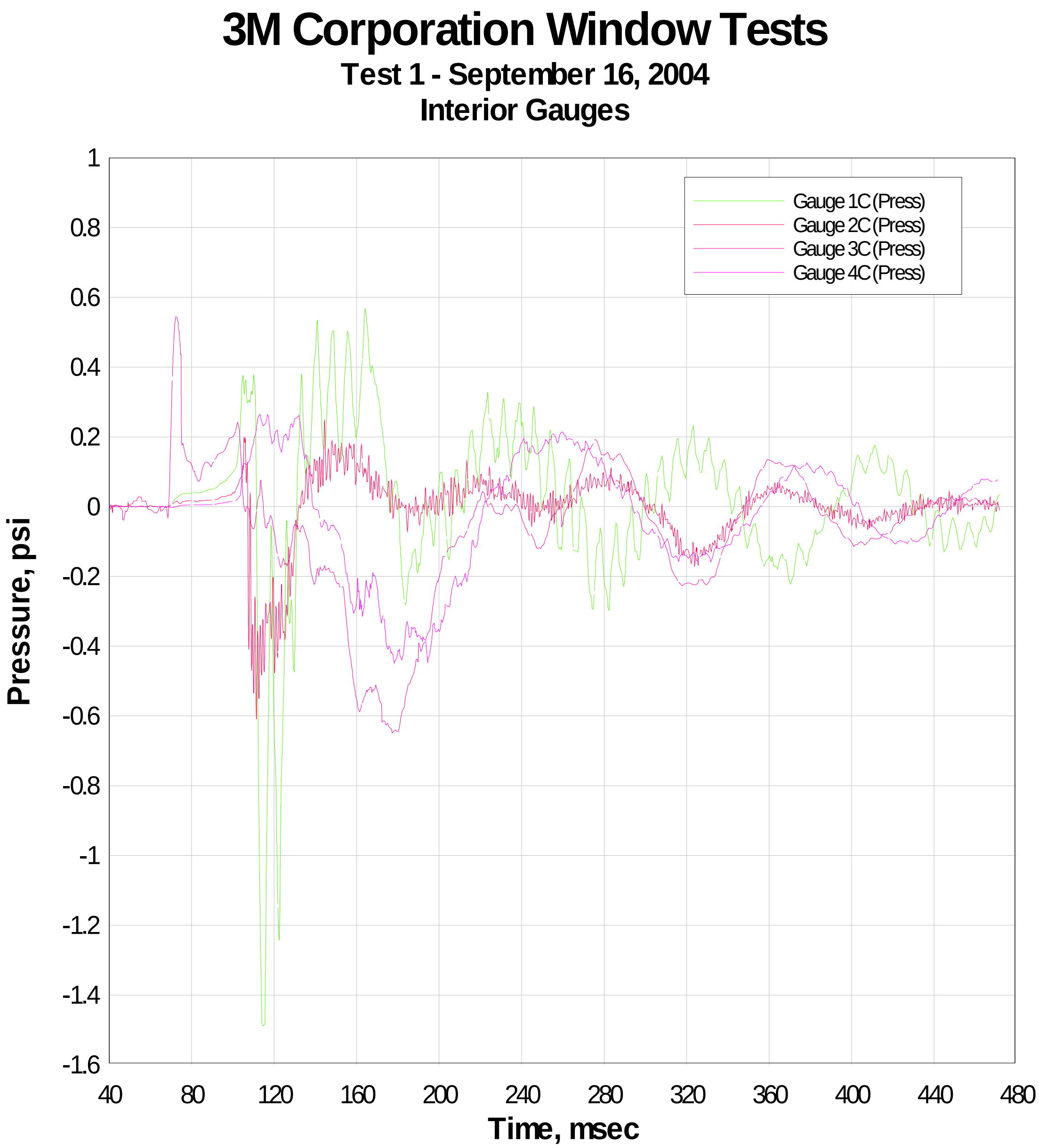


Figure B.3. Test 1, interior gauge pressure.

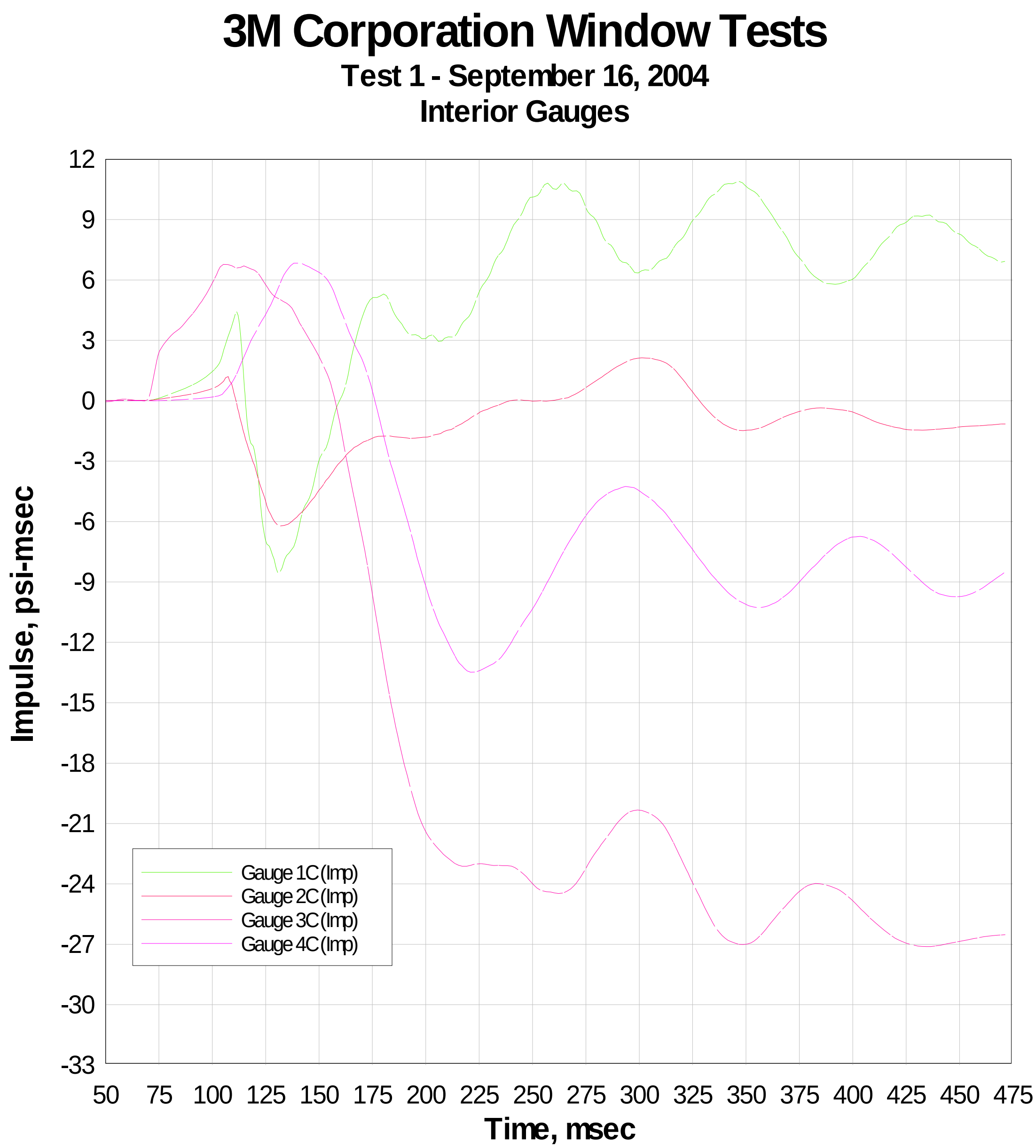


Figure B.4. Test 1, interior gauge impulse.

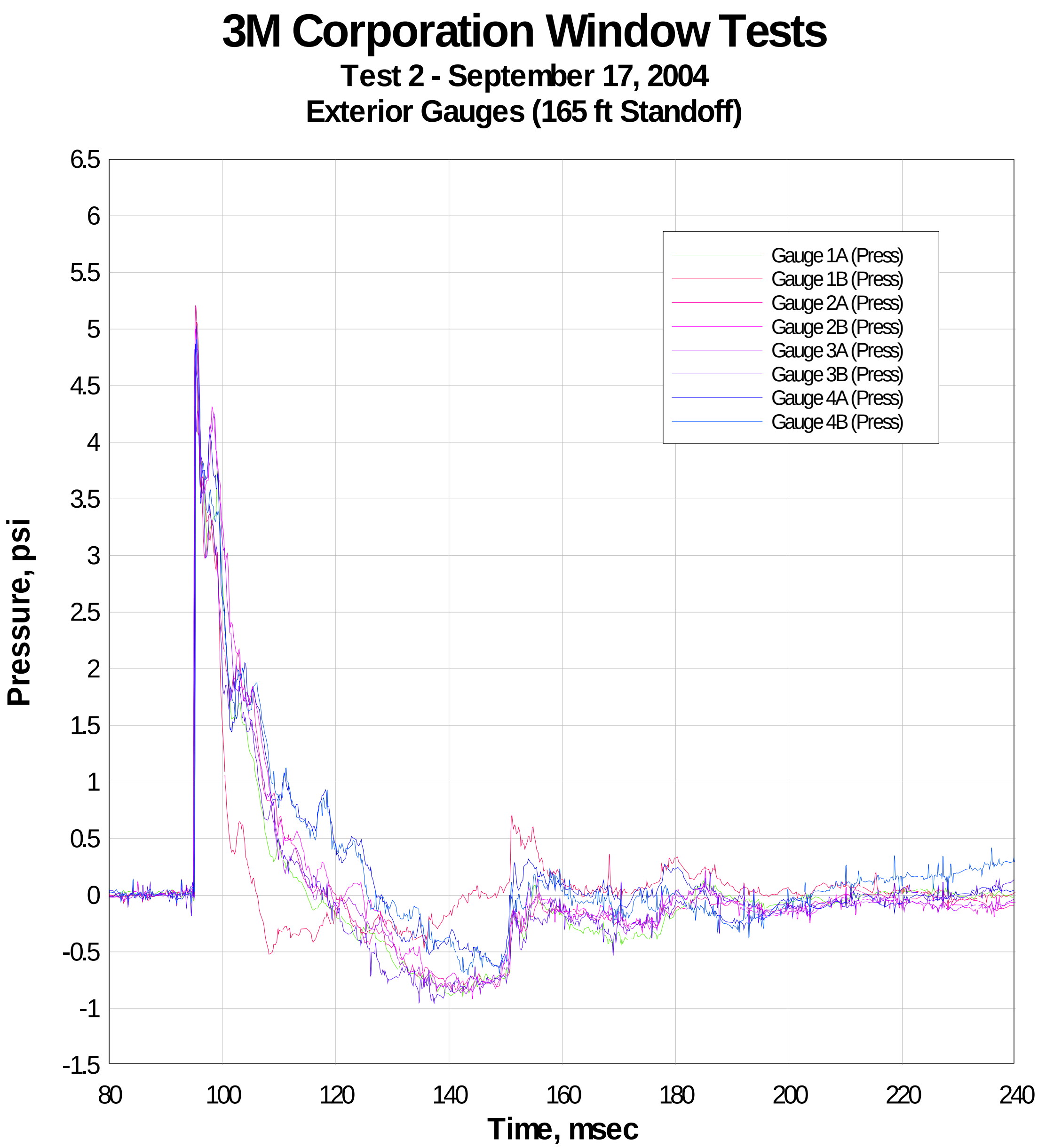


Figure B.5. Test 2, exterior gauge pressure.

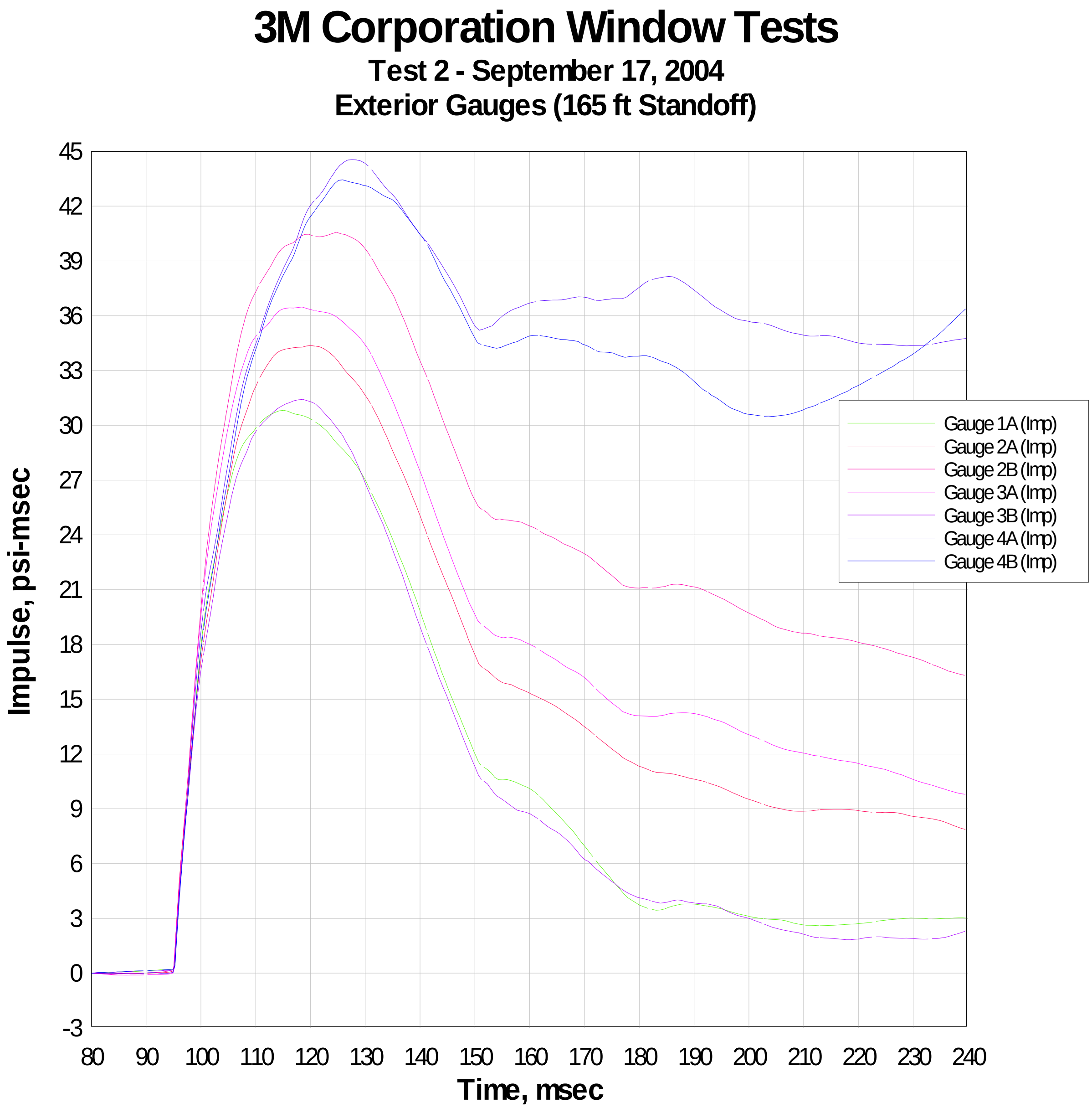


Figure B.6. Test 2, exterior gauge impulse.

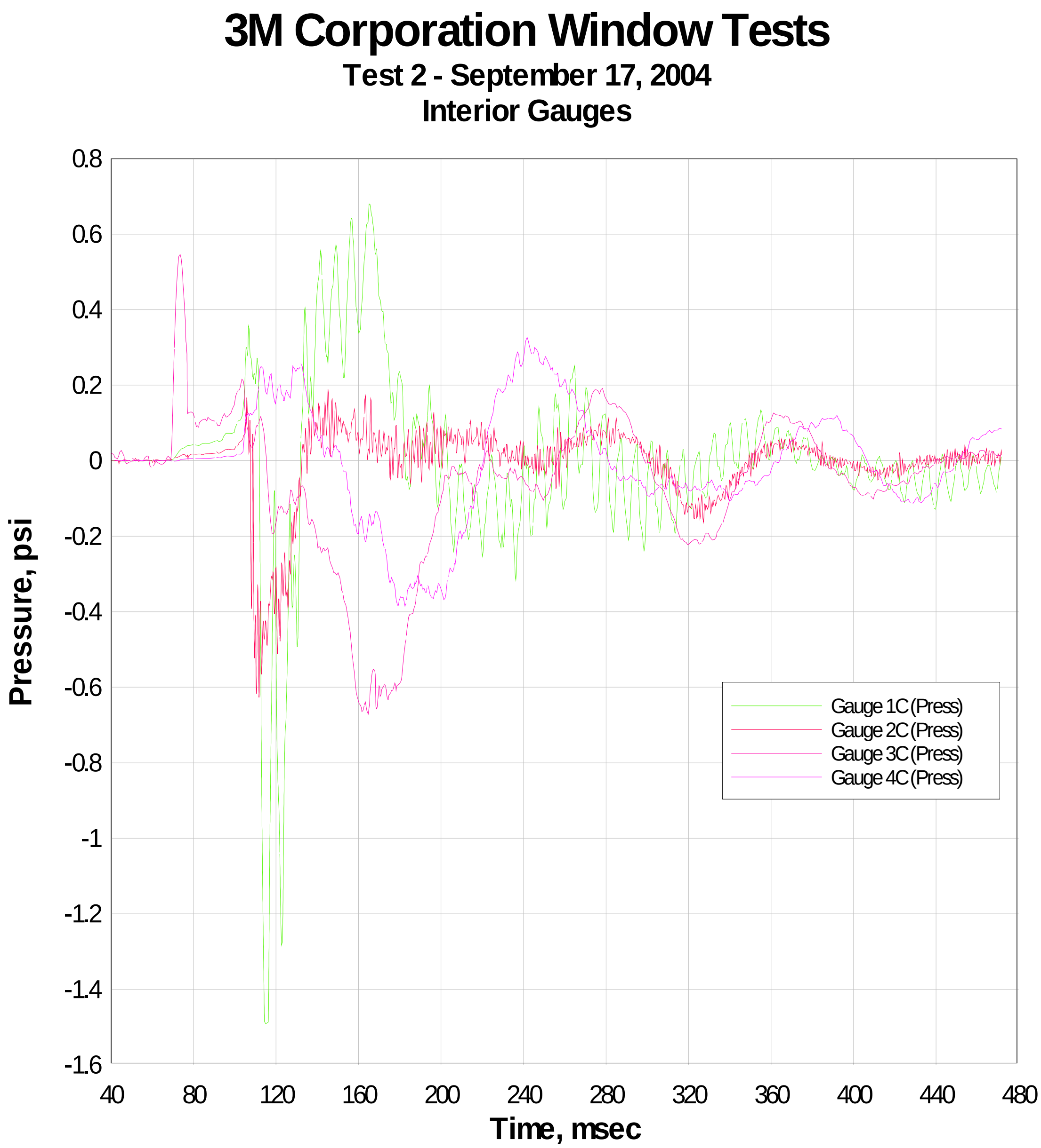


Figure B.7. Test 2, interior gauge pressure.

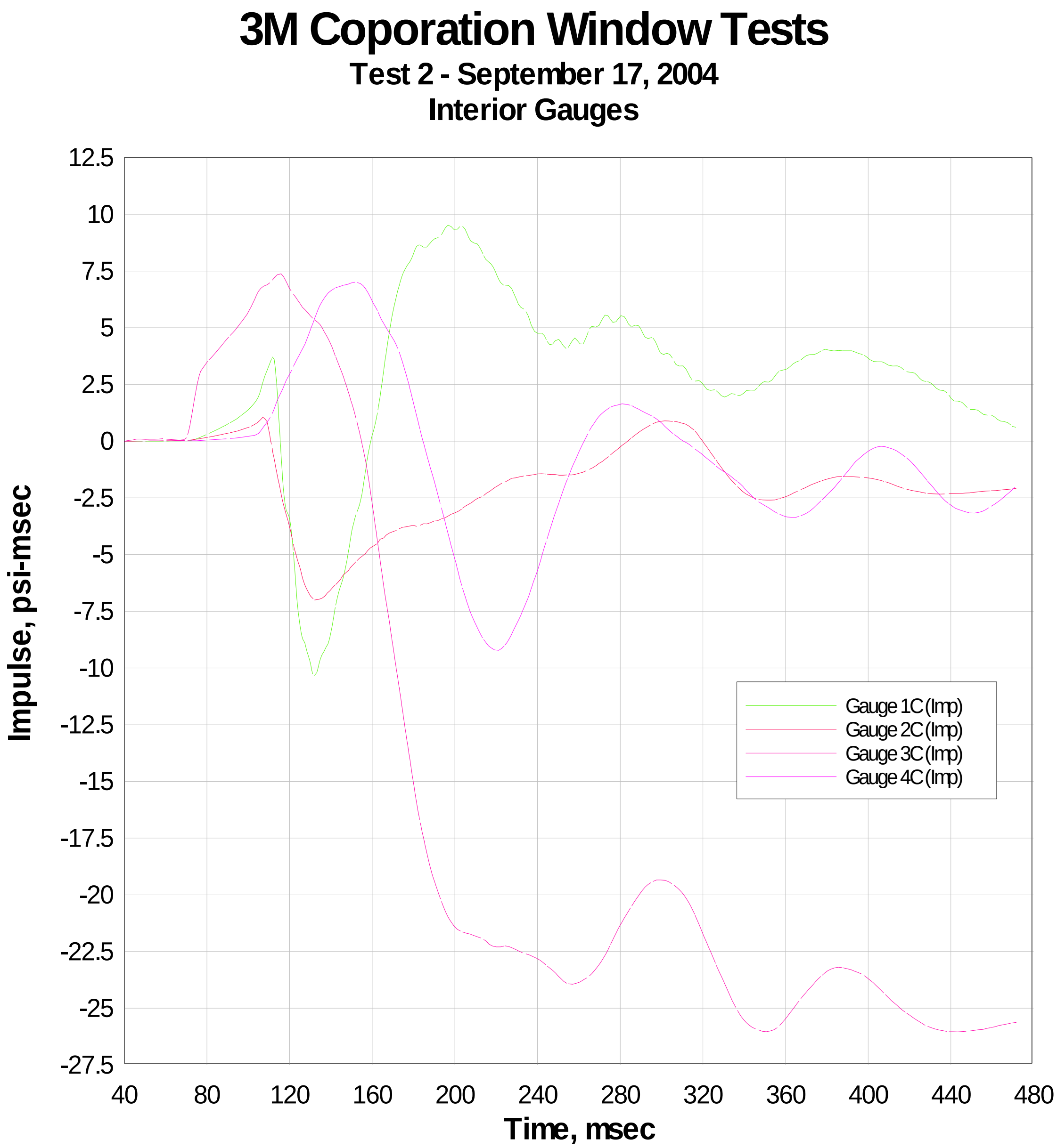


Figure B.8. Test 2, interior gauge impulse.

APPENDIX C

FRAME AND GLAZING DETAILS

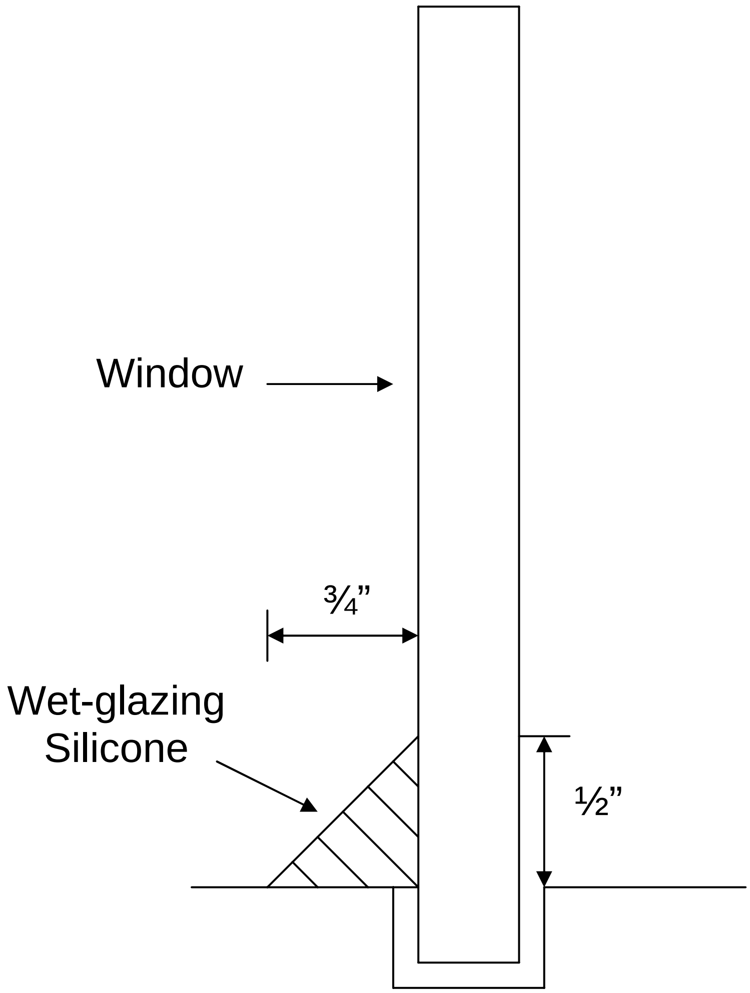
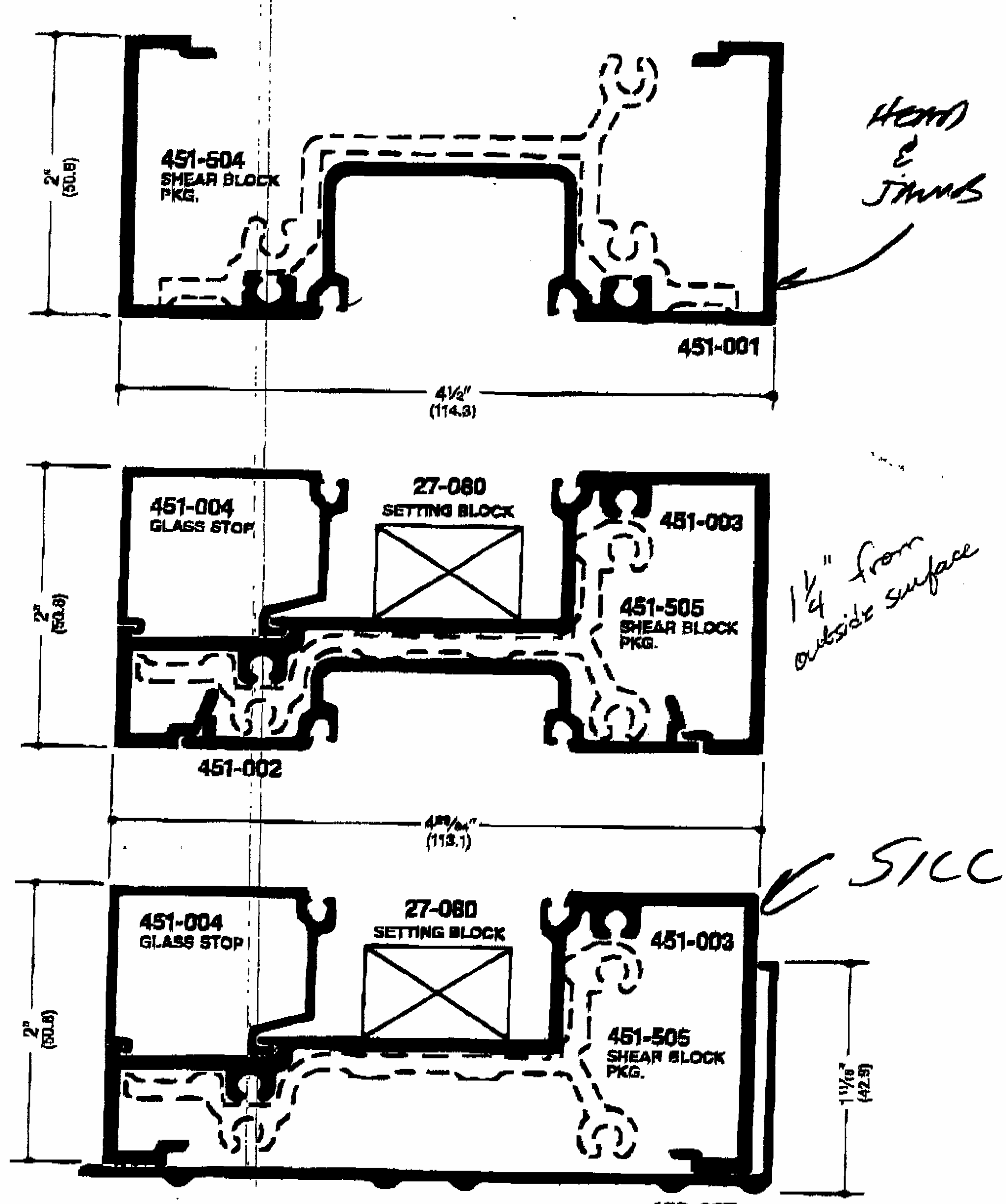


Figure C-1. Wet glazed window system.

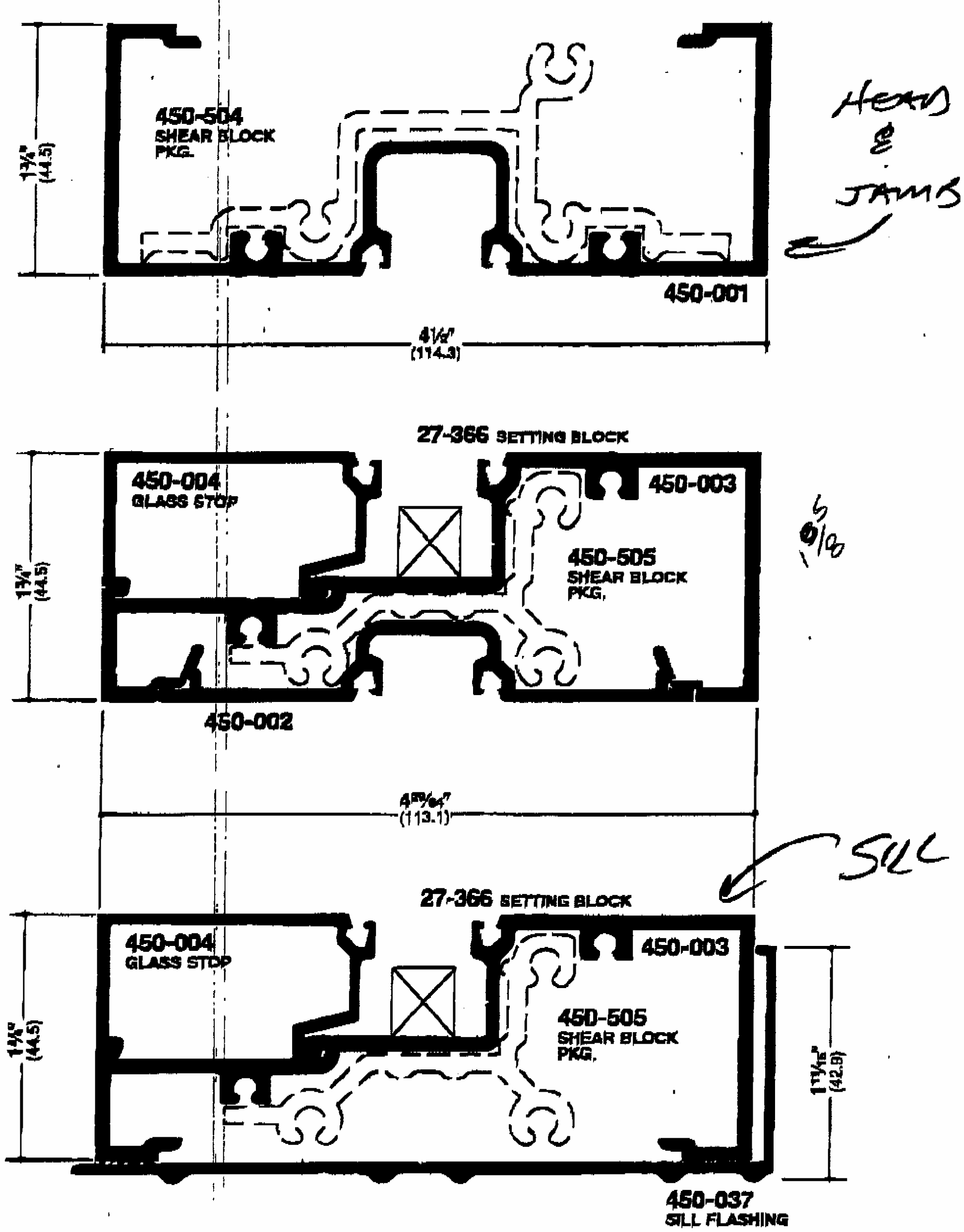
SCREW SPLINE SYSTEM 3



NOTE: SHEAR BLOCK PACKAGES SHOWN ARE FOR ATTACHMENT TO DOOR FRAMES.

TRIFAB® 451 — Kawneer — KAWNEER COMPANY INC

SCREW SPLINE SYSTEM 3



NOTE: SHEAR BLOCK PACKAGES SHOWN ARE FOR ATTACHMENT TO DOOR FRAMES.

TRIFAB® 450 — Kawneer — KAWNEER COMPANY, INC

APPENDIX D

GLASS FRAGMENT DISTRIBUTION

Table D.1. Glass Fragment Distribution.

Test #	Window #	Window Hazard Condition	Cubicle Region	Fragment Weight in Region (oz)	Total Fragment Unit Length under 10 inches (in) *
1	1	3b	3a	2.9	Greater Than 10
			3b	0.2	3 7/8
	2	3b	3a	3.6	Greater Than 10
			3b	0.5	9 1/2
	3	3b	3a	2.2	Greater Than 10
			3b	0.7	Greater Than 10
	4	3b	3a	2.5	Greater Than 10
			3b	0.4	8 11/32
2	1	3b	3a	3.2	Greater Than 10
			3b	10.4	Greater Than 10
	2	3b	3a	50.6	Greater Than 10
			3b	156.6	Greater Than 10
	3	3b	3a	3.5	Greater Than 10
			3b	3	Greater Than 10
	4	3b	3a	1.9	Greater Than 10
			3b	0.03	5 3/8

* Based upon guidelines provided in ASTM F 1642-04

3M Corporation Tests

Conducted September 16 -17, 2004

Post-Test Measurements

Collected Glass Fragment Distribution in Various Regions

Page 1

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Southern Division

JOB 3M Corp Explosive Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 1 Condition 3a (9/16) Test One

Fragments

1) 2 9/32 × 20/32 × 7/32 = 3 4/32"
2) 2 1/4 × 1 1/4 × 7/32 = 3 23/32"
3) 1 15/32 × 1 × 7/32 = 2 22/32"
4) 3 9/32 × 12/32 × 7/32 = 3 28/32"
5) 1 24/32 × 21/32 × 7/32 = 2 [illegible]/32"
6) 1 14/32 × 12/32 × 7/32 = 2 1/32"
7) 1 20/32 × 24/32 × 7/32 = 2 19/32"
8) 1 4/32 × 18/32 × 7/32 = 1 29/32"
9) 1 4/32 × 22/32 × 7/32 = 2 1/32"
10) 1 1/32 × 18/32 × 7/32 = 1 26/32"
11) 1 12/32 × 8/32 × 7/32 = 1 27/32"
12) 1 4/32 × 19/32 × 7/32 = 1 24/32"
13) 1 × 5/32 × 7/32 = 1 12/32"
14) 1 6/32 × 11/32 × 7/32 = 1 25/32"
15) 1 2/32 × 6/32 × 6/32 = 1 14/32"
16) 19/32 × 9/32 × 7/32 = 1 3/32"
17) 28/32 × 5/32 × 7/32 = 1 8/32"
18) 24/32 × 5/32 × 7/32 = 1 4/32"
19) 26/32 × [illegible] × 6/32 = 1 6/32"
20) 25/32 × 5/32 × 7/32 = 1 6/32"
21) 27/32 × [illegible] × 7/32 = 1 5/32"
22) 24/32 × 4/32 × 9/32 = 1 5/32"
23) 21/32 × 4/32 × 7/32 = 1 2/32"
24) 20/32 × 7/32 × 8/32 = 1 3/32"
25) 24/32 × 6/32 × 6/32 = 1 4/32"
26) 18/32 × 8/32 × 7/32 = 1 1/32"

Glazing Dust / Slivers

Weight = 0.5 oz

Fragments

Weight = 2.9 oz

Total Unit length > 10 inches, doesn't work

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Southern Division

JOB 3M Corp Explosive Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 1 Condition 3b (9/16) Test One

Fragments

1) 29/32 x 18/32 x 7/32 = 1 11/32
2) 24/32 x 18/32 x 7/32 = 1 12/32
3) 21/32 x 10/32 x 6/32 = 1 5/32

Total Unit Length = 3 28/32 inches < 10 inches ✓

Weight = 0.2 oz

Glazing Dust / Slivers

Weight = 0.2 oz

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Southern Division

JOB 3M Corp. Explosive Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 2 — Condition 3a (9/16) Test One

Fragments (inches)

1) 3 12/32 × 1 10/32 × 7/32 = 4 29/32
2) 2 8/32 × 1 6/32 × 7/32 = 3 21/32
3) 1 12/32 × 14/32 × 7/32 = 1 1/32
4) 1 21/32 × 21/32 × 7/32 = 2 17/32
5) 1 10/32 × 21/32 × 7/32 = 2 6/32
6) 1 11/32 × 25/32 × 7/32 = 2 19/32
7) 1 4/32 × 16/32 × 7/32 = 1 27/32
8) 21/32 × 19/32 × 7/32 = 1 15/32
9) 1 9/32 × 13/32 × 7/32 = 1 29/32
10) 1 12/32 × [illegible]/32 × [illegible]/32 = 2 [illegible]/32
11) 26/32 × 10/32 × 7/32 = 1 11/32
12) 25/32 × 17/32 × 7/32 = 1 20/32
13) 26/32 × 16/32 × 7/32 = 1 17/32
14) 24/32 × 16/32 × 7/32 = 1 15/32
15) 1 7/32 × 7/32 × 7/32 = 1 23/32
16) 1 5/32 × 8/32 × 7/32 = 1 20/32
17) 31/32 × 9/32 × 6/32 = 1 14/32
18) 1 2/32 × 10/32 × 7/32 = 1 19/32
19) 1 2/32 × [illegible]/32 × 7/32 = 1 20/32
20) 26/32 × [illegible]/32 × 7/32 = 1 [illegible]
21) 24/32 × 17/32 × 6/32 = 1 17/32
22) 25/32 × 7/32 × 6/32 = 1 6/32
23) 19/32 × 12/32 × 6/32 = 1 5/32
24) 24/32 × [illegible]/32 × 7/32 = 1 7/32

Glazing Dust / Slivers
Weight = 0.6 oz

Fragment Weight: 3.6 oz

Total Unit Length > 10 in, doesn't work

25) 31/32 × 6/32 × 6/32 = 1 11/32
26) 25/32 × 5/32 × 7/32 = 1 5/32
27) 1 7/32 × 8/32 × 8/32 = 1 19/32
28) 17/32 × 12/32 × 7/32 = 1 4/32
29) 21/32 × 12/32 × 7/32 = 1 8/32
30) 25/32 × 17/32 × 2/32 = 1 12/32
31) 20/32 × 10/32 × 7/32 = 1 5/32
32) 21/32 × 7/32 × 7/32 = 1 3/32
33) 19/32 × 11/32 × 6/32 = 1 4/32
34) 23/32 × 7/32 × 6/32 = 1 4/32
35) 30/32 × 7/32 × 4/32 = 1 9/32

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Southern Division

JOB 3M Corp. Explosive Testing
SHEET NO. ________ of ________
BY ________ DATE ________
PROJECT NO. ________

Test Structure 2 Condition 3b (9/16) Test One

Fragments (inches)

1) 1 9/32 × 31/32 × 9/32 = 2 17/32
2) 1 × 11/32 × 7/32 = 1 18/32
3) 23/32 × 13/32 × 6/32 = 1 10/32
4) 24/32 × 14/32 × 7/32 = 1 13/32
5) 15/32 × 11/32 × 7/32 = 1 1/32
6) 19/32 × 6/32 × 7/32 = 1
7) 22/32 × 6/32 × 5/32 = 1 1/32

\+ ______
9 16/32 inches

Total Unit Length = 9 16/32" < 10 inches ✓

Weight = 0.5 oz.

Glazing Dust / Slivers

Weight = 0.4 oz

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Southern Division

JOB 3M Corp. Exposure Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 3   Condition 3a (9/16) Test One

Fragments (inches)

1) 4 17/32 × 16/32 × 7/32 = 5 8/32
2) 1 25/32 × 1 13/32 × 7/32 = 3 17/32
3) 1 11/32 × 22/32 × 7/32 = 2 8/32
4) 1 × 29/32 × 7/32 = 2 4/32
5) 17/32 × 16/32 × 7/32 = 1 8/32
6) 1 5/32 × 16/32 × 7/32 = 1 28/32
7) 1 30/32 × 12/32 × 6/32 = 2 16/32
8) 18/32 × 11/32 × [illegible] = 1 4/32
9) 25/32 × 15/32 × 7/32 = 1 15/32
10) 1 25/32 × 12/32 × 7/32 = 2 12/32
11) 1 8/32 × 17/32 × 7/32 = 2
12) 1 6/32 × 11/32 × 7/32 = [illegible] 24/32
13) 1 2/32 × 2/32 × 3/32 = 1 7/32
14) 31/32 × [illegible] × 7/32 = 1 13/32
15) 19/32 × 12/32 × 8/32 = 1 [illegible]/32
16) 27/32 × 15/32 × 7/32 = 1 15/32
17) 24/32 × 14/32 × 7/32 = 1 13/32
18) 24/32 × 14/32 × 3/32 = 1 9/32
19) 20/32 × 12/32 × 7/32 = 1 7/32

Total Unit Length > 10 inches, doesn't work

Weight = 22 oz

Glazing Dust / Slivers

Weight = 0.5 oz

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APPLIED RESEARCH ASSOCIATES, INC.
Southern Division

JOB 3M [illegible] Explosive Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 3 Condition 3b (9/16) Test One

Fragments
1) 1 8/32 × 20/32 × 7/32 = 2 13/32
2) 30/32 × 20/32 × 4/32 = 1 24/32
3) 1 11/32 × 17/32 × 7/32 = 2 3/32
4) 30/32 × 7/32 × 7/32 = 1 12/32
5) 31/32 × 15/32 × 5/32 = 1 19/32
6) 1 3/32 × 6/32 × 5/32 = 1 11/32
7) 22/32 × 5/32 × 6/32 = 1 [illegible]
8) 25/32 × [illegible] × 4/32 = 1 3/32
9) 1 × 7/32 × 6/32 = 1 13/32
10) 24/32 × [illegible] × 7/32 = 1
11) 22/32 × 9/32 × 4/32 = 1
12) 14/32 × 6/32 × 7/32 = 1
13) [illegible] × [illegible] × 7/32 = 1 1/32

\+ 18 4/32 inches

Total Unit Length = 18 4/32" > 10 inches, doesn't [illegible].

Weight = 0.7 oz

Glazing Dust / Sliver

Weight: 34 oz

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Southern Division

JOB 3M Corp Explosive Testing
SHEET NO. ________ of ________
BY ________ DATE ________
PROJECT NO. ________

Test Structure 4

Condition 3a (9/16) Test One

Fragments (inches)

1) 3 9/32 × 14/32 × 7/32 = 4
2) 2 11/32 × 1 1/32 × 7/32 = 3 19/32
3) 1 12/32 × 11/32 × 7/32 = 1 31/32
4) 1 13/32 × 13/32 × [illegible] = 2 1/32
5) 1 4/32 × 12/32 × 7/32 = 1 23/32
6) 31/32 × 11/32 × 7/32 = 1 17/32
7) 1 4/32 × 10/32 × 7/32 = 1 21/32
8) 30/32 × 12/32 × [illegible] = 1 16/32
9) 1 18/32 × 14/32 × 7/32 = 2 7/32
10) 29/32 × 14/32 × 7/32 = 1 18/32
11) 1 5/32 × 7/32 × 7/32 = 1 19/32
12) 1 14/32 × 8/32 × 7/32 = 1 25/32
13) 1 6/32 × [illegible] × 7/32 = 1 29/32
14) 1 [illegible] × [illegible] × 7/32 = 1 9/32
15) 1 2/32 × 7/32 × [illegible] = 1 19/32
16) 27/32 × [illegible] × 7/32 = 1 12/32
17) 27/32 × 7/32 × 5/32 = 1 7/32
18) 25/32 × 7/32 × [illegible] = 1 11/32
19) [illegible] × [illegible] × 7/32 = 1 9/32
20) 1 2/32 × 7/32 × 7/32 = 1 16/32
21) 1 1/32 × 7/32 × [illegible] = 1 16/32
22) 29/32 × [illegible] × 7/32 = 1 15/32
23) 26/32 × 7/32 × [illegible] = 1 6/32
24) [illegible] × [illegible] × 7/32 = 1 14/32
25) [illegible] × [illegible] × [illegible] = 1 8/32
26) 24/32 × 7/32 × 6/32 = 1 5/32
27) 23/32 × 10/32 × 9/32 = 1 10/32
28) 22/32 × 12/32 × [illegible] = 1 9/32
29) 22/32 × 7/32 × 6/32 = 1 3/32
30) 22/32 × 8/32 × 6/32 = 1 4/32
31) 21/32 × 7/32 × 9/32 = 1 5/32
32) 13/32 × 16/32 × 7/32 = 1 4/32
33) 20/32 × 10/32 × 7/32 = 1 5/32
34) 21/32 × 8/32 × 4/32 = 1 1/32

Total Unit Length > 10 in, doesn't work

Weight : 2.5 oz

Glazing Dust / Slivers

Weight = 0.9 oz

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Southern Division

JOB 3M Corp. Explosive Testing
SHEET NO. ______ of ____
BY ______ DATE ______
PROJECT NO. ______

Test Structure 4 Condition 3b (9/16) Test One

Fragments (inches)

Weight = 0.3 oz

1) 28/32 × 20/32 × 4/32 = 1 22/32
2) 27/32 × 12/32 × 7/32 = 1 14/32
3) 1 3/32 × 4/32 × 7/32 = 1 14/32
4) 27/32 × 6/32 × 7/32 = 1 8/32
5) 24/32 × 7/32 × 4/32 = 1 7/32
6) 23/32 × 8/32 × 4/32 = 1 10/32
+ ______
8 11/32 inches

Total Unit Length = 8 11/32 inches < 10 inches ✓

Glazing Dust / Sliver

Weight = 0.4 oz

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Southern Division

JOB 3M Corp. Explosive Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 1

Condition 3a (9/17) Test Two

Fragments (inches)

1) 3 29/32 × 1 11/32 × 7/32 = 5 [illegible]/32
2) 3 20/32 × 1 8/32 × 7/32 = 5 3/32
3) 2 14/32 × 27/32 × 7/32 = 3 14/32
4) 2 12/32 × 29/32 × 7/32 = 3 14/32
5) 30/32 × 20/32 × 7/32 = 1 25/32
6) 1 4/32 × 13/32 × 7/32 = 1 24/32
7) 21/32 × [illegible] × 7/32 = 1 2/32
8) 20/32 × 14/32 × 7/32 = 1 9/32

Glazing Dust / Slivers
Weight = 0.2 oz

Total [illegible] length > 10 inches, doesn't work

Weight : 3.2 oz

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Southern Division

JOB 3M Corp. Exposure Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 1 Condition 3b (9/17) Test Two

Fragments (inches)

1) 1 29/32 × 1 15/32 × 7/32 = 3 19/32
2) 2 12/32 × 1 2/32 × 7/32 = 3 21/32
3) 1 26/32 × 1 24/32 × 7/32 = 3 27/32
4) 2 27/32 × 30/32 × 7/32 = 4
5) 2 3/32 × 27/32 × 7/32 = 3 4/32
6) 2 9/32 × 1 × 7/32 = 3 16/32
7) 1 14/32 × 21/32 × 7/32 = 2 22/32
8) 1 25/32 × 21/32 × 7/32 = 2 31/32
9) 1 17/32 × 1 1/32 × 7/32 = 2 20/32
10) 1 27/32 × 1 1/32 × 7/32 = 3 3/32
11) 1 22/32 × 26/32 × 7/32 = 2 25/32
12) 2 4/32 × 1 2/32 × 7/32 = 3 13/32
13) 1 5/32 × 29/32 × 7/32 = 2 8/32
14) 1 30/32 × 21/32 × 7/32 = 3 4/32
15) 1 21/32 × 22/32 × 7/32 = 2 19/32
16) 1 28/32 × 22/32 × 7/32 = 2 25/32
17) 1 7/32 × 13/32 × 7/32 = 1 27/32
18) 1 8/32 × 18/32 × 7/32 = 2 1/32
19) 1 16/32 × 22/32 × 7/32 = 2 16/32
20) 2 4/32 × [illegible] × [illegible] = 3 4/32
21) 1 9/32 × 1 [illegible] × 7/32 = 2 25/32
22) 1 29/32 × 12/32 × 7/32 = 2 16/32
23) 1 [illegible] × [illegible] × 7/32 = 2 3/32
24) 1 4/32 × 21/32 × 7/32 = 2
25) 1 17/32 × 1 2/32 × 7/32 = 2 26/32
26) 1 13/32 × 15/32 × 7/32 = 2 3/32
27) 1 4/32 × 25/32 × 7/32 = 2 11/32
28) 1 12/32 × 18/32 × 7/32 = 2 5/32
29) 2 × 18/32 × 7/32 = 2 25/32
30) 1 1/32 × 24/32 × 7/32 = 2
31) 1 14/32 × 15/32 × 7/32 = 2 6/32
32) 30/32 × 12/32 × 7/32 = 1 15/32
33) 1 10/32 × 21/32 × 7/32 = 2 6/32
34) 1 9/32 × 18/32 × 7/32 = 2 2/32
35) 1 4/32 × 17/32 × 7/32 = 2 28/32
36) 28/32 × 21/32 × 7/32 = 1 24/32
37) 31/32 × 16/32 × 7/32 = 1 22/32
38) 1 2/32 × 19/32 × 7/32 = 1 28/32
39) 26/32 × 14/32 × 7/32 = 1 15/32
40) 30/32 × 14/32 × 7/32 = 1 21/32
41) [illegible] × 14/32 × 7/32 = 1 19/32
42) 20/32 × 14/32 × 7/32 = 1 9/32
43) 21/32 × 14/32 × 7/32 = 1 12/32
44) 21/32 × [illegible] × 7/32 = 1 9/32
45) 15/32 × [illegible] × 7/32 = 1 7/32
46) 23/32 × 6/32 × 7/32 = 1 8/32
47) 23/32 × 15/32 × 7/32 = 1 12/32
48) 21/32 × [illegible] × 7/32 = 1 13/32
49) 14/32 × 2/32 × 7/32 = 1 6/32
50) 1 2/32 × 9/32 × 7/32 = 1 19/32
51) [illegible] × 14/32 × 7/32 = 1 3/32
52) 21/32 × 7/32 × 6/32 = 1 7/64
53) 20/32 × 12/32 × 7/32 = 1 7/32
54) 16/32 × 11/32 × 7/32 = 1 2/32
55) 22/32 × 10/32 × 4/64 = 1 4/32
56) 28/32 × 10/32 × 6/32 = 1 4/32
57) 18/32 × 12/32 × 7/32 = 1 5/32
58) 22/32 × 9/32 × 7/32 = 1 6/32
59) 22/32 × 17/32 × 2/32 = 1 2/32

Glazing Dust / Slivers

Weight = 0.4 oz

Weight for fragments = 10.4 oz

Total Unit Length > 10 inches, does [illegible] work

Applied Research Associates, Inc. 119 Monument Place Vicksburg, Mississippi 39180 601-638-5401 Fax: 601-634-0631

APPLIED RESEARCH ASSOCIATES, INC.
Southern Division

JOB 3M Corp [illegible] Testing
SHEET NO. ________ of ________
BY ________ DATE ________
PROJECT NO. ________

Test Structure 3

Condition 36 (9/17) Test Two

Fragments (inches)

1) 3 3/32 x 1 14/32 x 7/32 = 4 26/32
2) 1 13/32 x 1 11/32 x 7/32 = 2 31/32
3) 24/32 x 19/32 x 3/32 = 1 7/32
4) 1 x 27/32 x 3/32 = 1 27/32
5) 1 7/32 x 15/32 x 7/32 = 1 25/32
6) 1 1/32 x 17/32 x 7/32 = 1 25/32
7) 1 2/32 x 22/32 x 7/32 = 1 31/32
8) 1 4/32 x 15/32 x 7/32 = 1 26/32
9) 1 14/32 x 14/32 x 7/32 = 2 7/32
10) 30/32 x 14/32 x 7/32 = 1 19/32
11) 1 1/32 x 11/32 x 7/32 = 1 19/32
12) 26/32 x 12/32 x 7/32 = 1 13/32
13) 24/32 x 17/32 x 7/32 = 1 14/32
14) 29/32 x 12/32 x 7/32 = 1 16/32
15) 19/32 x 27/32 x 7/32 = 1 14/32
16) 26/32 x 10/32 x 7/32 = 1 11/32
17) 31/32 x 9/32 x 7/32 = 1 15/32
18) [illegible] x 14/32 x [illegible] = 1 15/32
19) 24/32 x 14/32 x 7/32 = 1 13/32
20) 24/32 x 13/32 x 7/32 = 1 12/32
21) 24/32 x [illegible] x [illegible] = 1 15/32
22) 25/32 x 15/32 x 7/32 = 1 19/32
23) 28/32 x 7/32 x [illegible] = 1 9/32
24) 29/32 x 11/32 x 7/32 = 1 6/32
25) 20/32 x 17/32 x 7/32 = 1 8/32
26) 1 x 9/32 x 4/32 = 1 14/32
27) 21/32 x 7/32 x 7/32 = 1 6/32
28) 1 13/32 x 4/32 x 2/32 = 1 21/32
29) 20/32 x 17/32 x 7/32 = 1 5/32
30) 20/32 x 9/32 x 4/32 = 1 1/32

Glazing Dust / Sliver

Weight = 1.5 oz

Total Unit Length > 10 inches
doesn't work

Fragment Weight = 3.0 oz

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Test Structure 1 Condition 2a (9/17) Test Two

Fragments (inches)

1) 3 21/32 × 9/32 × 7/32 =
2) 2 6/32 × 28/32 × 7/32 =
3) 1 1/32 × 18/32 × 7/32 =
4) 23/32 × 11/32 × 7/32 =
5) 1 20/32 × 14/32 × 7/32 =
6) 1 10/32 × 7/32 × 6/32 =
7) 1 13/32 × 15/32 × 7/32 =
8) 24/32 × 15/32 × 7/32 =
9) 1 3/32 × 7/32 × 1/32 =
10) 1 11/32 × 13/32 × 5/32 =
11) 26/32 × 19/32 × 7/32 =
12) 1 5/32 × 13/32 × 7/32 =
13) 19/32 × 15/32 × 7/32 =
14) 18/32 × 15/32 × 7/32 =
15) 26/32 × 11/32 × 7/32 =
16) 1 11/32 × 15/32 × 5/32 =
17) 31/32 × 15/32 × 4/32 =
18) 1 2/32 × 13/32 × 7/32 =
19) 1 2/32 × 9/32 × 7/32 =
20) 27/32 × 11/32 × 7/32 =
21) 21/32 × 9/32 × 7/32 =
22) 24/32 × 11/32 × 7/32 =
23) 25/32 × 7/32 × 7/32
24) 1 3/32 × 9/32 × 4/32 =
25) 24/32 × 7/32 × 7/32 =
26) 30/32 × 9/32 × 7/32 =
27) 24/32 × 10/32 × 7/32 =
28) 18/32 × 13/32 × 5/32 =
29) 20/32 × 15/32 × 7/32 =
30) 1 8/32 × 7/32 × 4/32 =
31) 21/32 × 10/32 × 7/32 =
32) 1 4/32 × 7/32 × 4/32 =
33) 25/32 × 7/32 × 7/32 =
34) 14/32 × 13/32 × 5/32 =
35) 15/32 × 7/32 × 7/32 =

Weight = 1.9 oz

Total unit length ≥ 10 inches, doesn't work

Glazing Dust & Slivers
Weight = 0.7 oz

APPLIED RESEARCH ASSOCIATES, INC.
Southern Division

JOB 3M Corp. Fire Testing
SHEET NO. ______ of ______
BY ______ DATE ______
PROJECT NO. ______

Test Structure 4 Condition 3B (9/17) Test Two

Fragments (Curtain)

1) 29/32 × 14/32 × 7/32 = 1 18/32
2) 31/32 × 13/32 × 7/32 = 1 19/32
3) 18/32 × 9/32 × 7/32 = 1
4) 1 × 5/32 × 2/32 = 1 7/32

+ 5 12/32"

Total Char Length = 5 12/32 inches < 10 inches ✓

Weight = 0.03 oz

Ebony Dust & Cinders
Weight = 0.4 oz