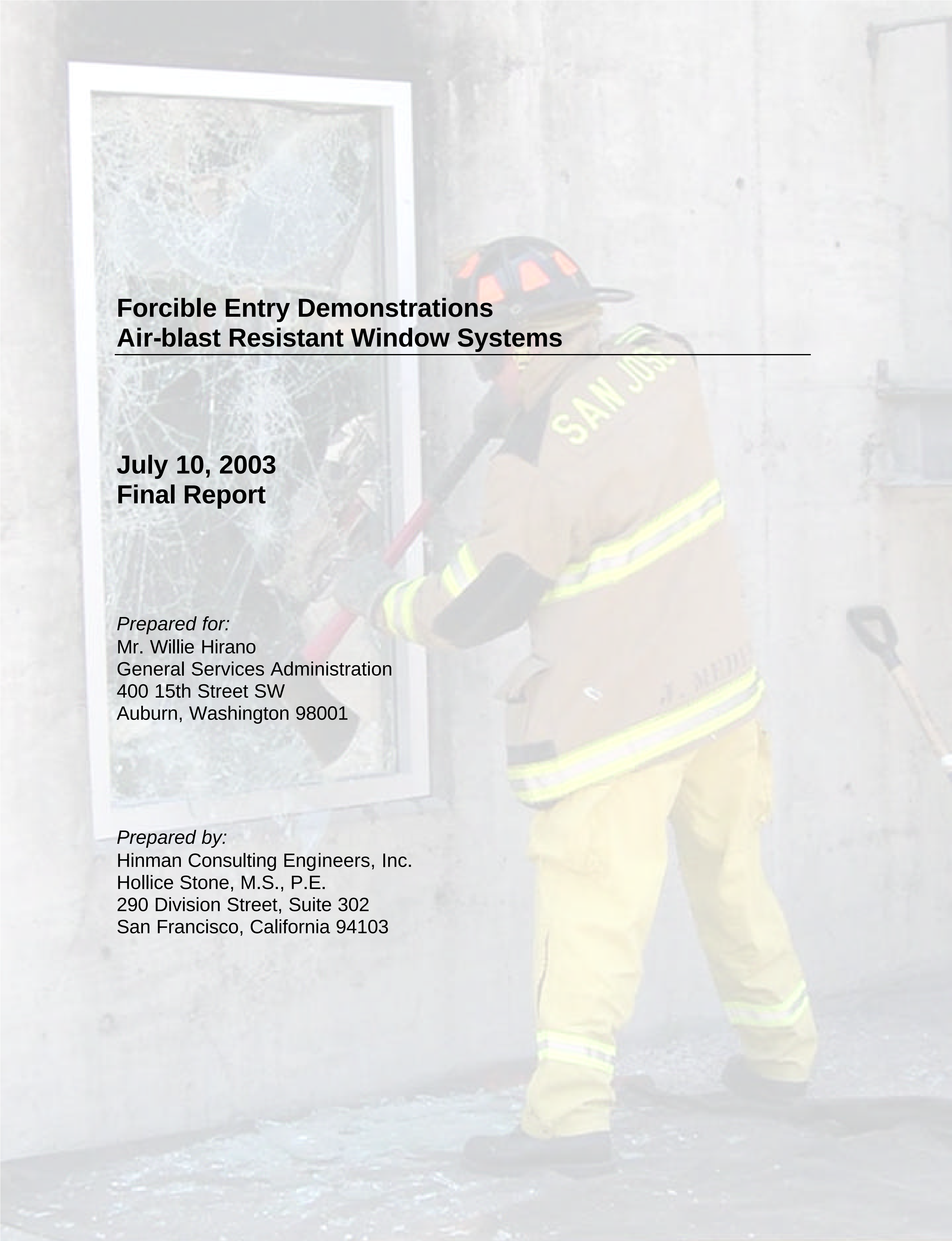

Forcible Entry Demonstrations
Air-blast Resistant Window Systems

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Final Report

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Executive Summary

The General Services Administration (GSA) and other government agencies are retrofitting the windows of existing buildings to mitigate the effects of flying glass in the event of an explosive terrorist attack. Little is known about the consequences such retrofits can have for emergency responders who may need to gain emergency access and/or egress through windows. The GSA and the Department of Homeland Security (DHS) contracted with Hinman Consulting Engineers, Inc., to perform forcible entry testing of certain selected air-blast-resistant windows and window retrofit systems commonly found in GSA buildings nationwide. In collaboration with the Protective Glazing Council, and the San Jose Fire Department, Hinman Consulting Engineers, Inc., conducted these tests on May 28, 2003. This report lists the window configurations tested, describes the procedures employed, and summarizes the findings of the tests.

Over the past twenty years, the federal government has been retrofitting the windows of existing buildings to mitigate the effects of explosive attacks. Recently, the number of available air-blast-mitigating retrofits has expanded, as has the number of buildings receiving retrofits. This increases the potential for firefighters to find these enhanced window systems on buildings during fire and other emergencies.

The windows and window treatments included in these demonstrations were selected to represent an array of configurations representative of the most prevalent air-blast resistance window retrofits and upgrades. This is not considered to be a complete catalog of all air-blast-resistant retrofits or window types. The samples were chosen to answer the basic question of whether forcible entry of typical air-blast-resistant window systems is possible using standard firefighting tools. Table ES-1 lists window configurations addressed in these demonstrations.

Table ES-1. Window Configurations

Air-blast-Resistant System	Glass Type	Attack Side	Floor Level
Daylight film	AG	Exterior	1
	AG	Interior	1
	AG	Exterior	2
	TTG	Exterior	1
	TTG	Interior	1
Four-sided attached film	TTG	Exterior	2
	AG	Exterior	1
	AG	Interior	1
Four-sided attached film with center seam	AG	Exterior	1
	AG	Interior	1
	TTG	Exterior	1
Two-sided attached film	TTG	Interior	1
Two-sided attached film with center seam	TTG	Interior	1
Single-paned laminated glass with 0.030-inch interlayer	AG	Exterior	1
	AG	Interior	1
Single-paned laminated glass with 0.060-inch interlayer	TTG	Exterior	1
	TTG	Interior	1
	TTG	Exterior	2
Insulating glass units with inner pane laminated	AG	Exterior	1

Air-blast-Resistant System	Glass Type	Attack Side	Floor Level
with 0.030-inch interlayer	AG	Interior	1
	AG	Exterior	2
Insulating glass units with inner pane laminated with 0.060-inch interlayer	AG	Exterior	1
	AG	Interior	1
Insulating glass units with inner pane laminated with 0.090-inch interlayer	AG	Exterior	1
	AG	Interior	1
	AG	Exterior	2
Untreated glass	AG	Exterior	1

San Jose Fire Department firefighters from Engine Company 2 and Ladder Company 2 were used for the forcible entry demonstrations. The firefighters first attempted forcible entry using the standard forcible entry tools and operating procedures of the San Jose Fire Department and the International Fire Service Training Association (IFSTA).

The firefighters were able to enter all of the window mock-ups with conventional firefighting tools such as axes, hooligans' tools, and pike poles. Though conventional tools were equal to the job, updated techniques were required to efficiently break and clear the windows. However, based on observations made during the demonstrations, additional questions were raised which should be addressed in future demonstrations. Recommendations to address these questions include:

- Additional Forcible Entry Tests

  Though the window systems tested encompassed a variety of common retrofits, additional widely-used configurations should be tested.

- Emergency egress through air-blast-resistant windows under live fire conditions
- Additional Air-blast Testing

  Before a center-seam configuration with a two-sided attached window film is used for an air-blast resistant application, air-blast testing should be performed to ensure that the configuration meets performance requirements.

- Information Exchange

  The transfer of information on the implications to forcible entry of air-blast resistant window systems should be made a priority by entities involved in the installation of these window systems.

1. Introduction

The General Services Administration (GSA) and other government agencies are retrofitting the windows of existing buildings to mitigate the effects of flying glass in the event of an explosive terrorist attack. Little is known about the consequences such retrofits can have for emergency responders who may need to gain emergency access and/or egress through windows. The GSA and the Department of Homeland Security (DHS) contracted with Hinman Consulting Engineers, Inc., to perform forcible entry testing of certain selected air-blast-resistant windows and window retrofit systems commonly found in GSA buildings nationwide. In collaboration with the Protective Glazing Council, and the San Jose Fire Department, Hinman Consulting Engineers, Inc., conducted these tests on May 28, 2003. This report lists the window configurations tested, describes the procedures employed, and summarizes the findings of the tests. On the basis of these tests and findings, we suggest additional tests to further explore the potential challenges encountered by firefighters operating in buildings which have been retrofitted to mitigate explosive effects. A glossary of terminology is included.

2. Background

Over the past twenty years, the federal government has been retrofitting the windows of existing buildings to mitigate the effects of explosive attacks, often installing window film on the interior side of existing windows to hold glass shards together after the glass breaks. As technology has advanced and the perceived likelihood of attack has increased, the types of available air-blast-mitigating retrofits have expanded, as has the number of buildings receiving retrofits. The federal government is not alone in making a coordinated effort to evaluate and retrofit its buildings; private landlords are beginning to see the advantages in protecting their buildings' occupants from potential attack.

The GSA is the nation's largest property manager, in charge of federal office buildings and courthouses nationwide. As the number of buildings undergoing window retrofit grows, the probability of firefighters encountering these retrofitted windows during emergency operations increases. This raises the question of whether firefighters will be able to rapidly effect forcible entry and exit through these retrofitted windows with standard tools and procedures.

These demonstrations were designed to address that question. We investigated the potential effects of air-blast-resistant windows and retrofits on forcible access and egress procedures of firefighters during emergency operations. The purpose was to sample and time tools and techniques which may be used by firefighters to break windows which have been designed and/or retrofitted for air-blast resistance.

2.1. The Effects of Explosions on Glass

Window systems are a concern when mitigating the effects of explosions because glass is often the weakest part of a building, breaking at low pressures compared to other components such as the floors, walls, or columns. High-velocity glass fragments have been shown to be a major contributor to injuries in such events. In the bombing of the Alfred P. Murrah Building in Oklahoma City, for instance, 40% of the survivors within the Murrah Building cited glass as contributing to their injuries. Within nearby buildings, laceration estimates ranged from 25% to 30% [1].

Not just the targeted building's windows are affected by the explosive forces; past incidents have shown that glass breakage may extend for miles in large external explosions. Also, for explosions within downtown city areas full of glass-clad high-rise buildings, falling glass poses a major hazard to passersby and prolongs post-incident rescue and clean-up efforts by leaving tons of glass debris on the street.

Explosion-related injuries are classified as primary, secondary, and tertiary. Glass breakage contributes to all three of these injury groups. The high pressure of the air-blast that enters through broken windows may cause eardrum damage and lung collapse (or "primary" injuries). As the air-blast damages the building components in its path, debris becomes missiles which cause impact injuries (or "secondary" injuries). Airborne glass fragments typically cause penetration- or laceration-type injuries. Larger (non-glass) fragments may cause non-penetrating, or blunt trauma injuries. Finally, the air-blast pressures cause occupants to be bodily thrown against objects or to fall ("tertiary" injuries). These effects are summarized in Table 1.

Table 1. Explosion-Related Injury Types

Injury Classification	Injury Type	Cause
Primary	Eardrum rupture, lung collapse	Air-blast pressure levels
Secondary	Lacerations and blunt trauma injuries	Missile impact
Tertiary	Being thrown or falling due to the force of the explosion	Air-blast pressure impact

3. Standard Forcible Entry Procedures

Although every fire department has unique standard operating procedures, the following steps outline fundamental elements which all departments' procedures incorporate in some manner:

- Access into burning structure for rescue or fire attack
  - From the exterior
  - Generally made on the first several floor levels
- Venting the fire
  - From exterior or interior, depending on the department's protocols and the specific situation
  - Any floor level
- Egress from the building, sometimes under emergency conditions
  - From the interior
  - From any floor level

4. Terminology

One barrier to the free and easy exchange of information among government agencies, building managers, engineers, manufacturers, fire departments, and firefighters is that these different groups of people often use different words to describe identical ideas. An example of this are the terms used to refer to two layers of glass which are bonded together with an interlayer. The building and engineering communities refer to this as laminated glass and the fire service refers to this as safety glass. Appendix A presents various terms, as they are used in this report.

5. Window Configurations

The windows and window treatments included in these demonstrations were selected to represent an array of configurations representative of the most prevalent air-blast resistance window retrofits and upgrades. This is not considered to be a complete catalog of all air-blast-resistant retrofits or window types. The samples were chosen to answer the basic question of whether forcible entry of typical air-blast-resistant window systems is possible using standard firefighting tools.

Table 2 lists the window types tested. AG refers to annealed glass and TTG refers to thermally-tempered glass. All glass is ¼" thick. The bites on the laminated glass were standard for the window industry (3/8"). The single-paned laminated windows were wet glazed at the interior surface and dry glazed at the exterior. The insulating glass units were dry glazed. All film was 7 mil (0.007 inches) in thickness and was mechanically attached, when an attached system was used.

Appendix C presents the full test-day data table with all tests listed in order.

Table 2. Window Configurations Tested

Air-blast-Resistant System	Glass Type	Attack Side	Floor Level	Test Number
Daylight film	AG	Exterior	1	1
	AG	Interior	1	2
	AG	Exterior	2	24
	TTG	Exterior	1	3
	TTG	Interior	1	4
Four-sided attached film	TTG	Exterior	2	25
	AG	Exterior	1	5
	AG	Interior	1	6
Four-sided attached film with center seam	AG	Exterior	1	7
	AG	Interior	1	8
	TTG	Exterior	1	9
Two-sided attached film	TTG	Interior	1	11
Two-sided attached film with center seam	TTG	Interior	1	10
Single-paned laminated glass with 0.030-inch interlayer	AG	Exterior	1	14
	AG	Interior	1	15
Single-paned laminated glass with 0.060-inch interlayer	TTG	Exterior	1	17
	TTG	Interior	1	16
	TTG	Exterior	2	26

Air-blast-Resistant System	Glass Type	Attack Side	Floor Level	Test Number
Insulating glass units with inner pane laminated with 0.030-inch interlayer	AG	Exterior	1	18
	AG	Interior	1	19
	AG	Exterior	2	27
Insulating glass units with inner pane laminated with 0.060-inch interlayer	AG	Exterior	1	20
	AG	Interior	1	21
Insulating glass units with inner pane laminated with 0.090-inch interlayer	AG	Exterior	1	22
	AG	Interior	1	23
	AG	Exterior	2	28
Untreated glass	AG	Exterior	1	12

The untreated annealed glass configuration (Test 12) was used as a control sample to demonstrate how a standard annealed glass window would break, and the associated times.

6. Demonstration Procedure

Firefighters from the San Jose Fire Department effected emergency access and egress through the air-blast-resistant windows mock-ups using typical tools and procedures. This section describes the specific elements of the demonstrations.

6.1. Demonstration Structure

All window mock-ups were mounted in the San Jose Fire Department's training tower at the department's training center at 255 South Montgomery Street in San Jose, California.

The walls of the training tower are cast-in-place concrete and the rough window openings are 36 inches wide by 60 inches high. The glass and framing window mock-ups were mounted in steel frames which were mounted in the rough window openings.

6.2. Demonstration Participants

San Jose Fire Department firefighters from Engine Company 2 and Ladder Company 2 were used for the forcible entry demonstrations. All participating firefighters were of average size, and had experience with real life forcible entry in emergency operations.

6.3. Tools and Techniques

The firefighters first attempted forcible entry using the standard forcible entry tools and operating procedures of the San Jose Fire Department and the International Fire Service Training Association (IFSTA). All tools used in the tests are commonly carried on fire apparatus or by firefighters throughout the United States. Entry was restricted to gaining access through the glass itself and not by prying the window framing from the wall. If the firefighters did not gain access with these limitations, provisions were made for the use of more sophisticated tools. In this set of demonstrations, more sophisticated tools were not required.

6.4. Data Collection

A recorder/timer was assigned to gather the following information for each test:

- Test number
- Window Configuration
- Exterior or interior attack
- First or second floor
- Firefighter ID
    - Name
    - Company
    - Number of years' experience
    - Weight
- Start time
- Time to first break
- Time to vent
- Time to clear
- Tools used
- Comments from the firefighter performing the demonstration

6.5. Documentation

Each test was videotaped from one position from first attack to the final clear of the window. After each demonstration, the firefighter performing the break commented on the process.

In addition to the videotaping, the tests were also photographed. Still photographs were taken of the post-demonstration condition of each window.

6.6. Tools

Standard firefighting tools were used for these demonstrations, and included the following:

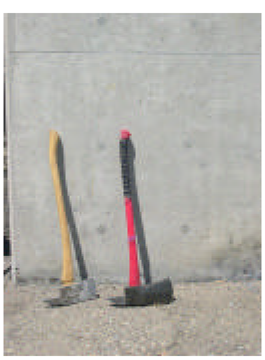

Figure 2: Pickhead Axes (6 lb and 8 lb)

Figure 1: Hooligan Tool

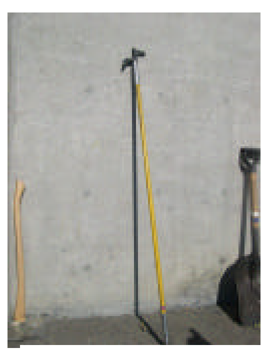

Figure 3:

New York Roof Hook

7. Findings

Firefighters were able to clear all of the windows, but the average time to clear varied among the different types of treatment. The table presented in this section describes averaged results only; the test results in their entirety are given in Appendix C.

Brief descriptions of the results of the tests of each type of window follow.

7.1. Average Times

Table 3 shows the clear times (if only one window of a particular type was tested) and average clear times (if more than one window of a particular type was tested) for first floor access and egress for the different window types. The fastest time was for the thermally-tempered glass with daylight film and the longest times were for the windows with four-sided attached film.

Table 3. Average Times

Air-blast-Resistant System	Glass Type	Average Time to Break (seconds)	Average Time to Vent (seconds)	Average Time to Clear (seconds)
Daylight film	AG	2	8.7	33.5
	TTG	1.5	3.5	7.5
Four-sided attached film	AG	2.5	5	39.0
	TTG	26	26	64 (one test only)
Four-sided attached film with center seam	AG	1.5	5.5	28.5
	TTG	2	3	35.0 (one test only)
Two-sided attached film	TTG	6	15	30.0 (one test only)
Two-sided attached film with center seam	TTG	1	2	26.0 (one test only)
Single-paned laminated glass	AG	6	13.5	27.5
	TTG	4.5	9.5	15.0
Insulating glass units with inner pane laminated	AG	12.7	17.5	29.0
Untreated glass	AG	1	1	24.0 (one test only)

7.2. Daylight Film Application

7.2.1. Annealed Glass

In one case, the film appeared to make the first break more difficult (four seconds for the window with film versus one second on the control – untreated – window). Venting took longer for the window with the film (average of twelve seconds with film versus one second on the control window). A beneficial side effect of the film treatment is enhanced safety for personnel on lower levels when firefighters attack from an upper floor, due to the decreased number of shards falling.

Figure 4: Test 1 Annealed Glass with Daylight Film

7.2.2. Tempered Glass

Overall, it was easier to make entry through tempered glass with daylight film than through annealed glass with daylight film. However, though entry was still rapid, the film caused a delay over what would be expected (based on the past experience of the participating firefighters) from an untreated tempered glass window. Additionally, no shards remained in the frames after the breaks.

Figure 5: Test 3 Tempered Glass with Daylight Film

7.3. Mechanically Attached Film Application

Two methods of film attachment were tested, two-sided and four-sided. Clearing the attached film required the firefighters to chop the film away from the framing at all attached sides. The time statistics in Table 3 show the effects of the attachment on time to clear.

The best technique employed over the course of the testing was to clear the top, clear halfway down the two sides, then the bottom, followed by the remainder of the sides.

The presence of a center seam made no appreciable difference in the ease or speed of forcible entry for the four-sided attached film, but it made a significant difference in the two-sided attached film (vent for no seam was 15 seconds and vent with a seam was two seconds). However, a seam located parallel to the attachment sides for a two-sided attached application has not been tested for air-blast resistance.

7.3.1. Annealed Glass

Times recorded for the four-sided attached film on annealed glass were comparable to those for the daylight film on annealed glass.

Figure 6: Test 6 Annealed Glass with 4-Sided Attached Film Without Center Seam

7.3.2. Tempered Glass

The film created a delay compared to typical break and clear times expected with untreated tempered glass, especially on the second floor where the time to first break was 26 seconds and the time to clear was 64 seconds.

The times to first break and vent were greater for the second-story tempered glass than for the second-story annealed glass (tempered – 26 seconds to break and vent and annealed – four seconds to break and ten seconds to vent), though the final clear times were comparable (64 seconds for tempered and 71 seconds for annealed).

Figure 7: Tempered Glass 4-Sided Attached Film with Center Seam

7.4. Laminated, Single-Paned Glass

The laminated, single-paned window panes became a flexible mass when broken, especially the tempered glass panes. This allowed the firefighter to use the weight of the tool to push the entire unit out of the framing system rather than requiring them to chop around the entire window perimeter, as was done for the attached window film systems. This tended to decrease the time for venting and clearing of the windows.

Break, vent, and clear times for the laminated single-paned units were comparable to the daylight film configurations, but were less than for the attached-film configurations. Heavier tools tended to improve the vent and clear times.

As with the tempered glass with daylight film, no glass shards remained in the frame after the break.

Figure 8: Test 26 Laminated Single Paned Tempered Glass

7.5. Laminated Insulating Glass Units

First break for the laminated annealed insulating glass units was approximately twice that of the first break time for the single-paned laminated annealed insulating glass units. The firefighters found that a good way to gain access through insulting glass units was to first ensure that the non-laminated annealed panes were fully broken before addressing the laminated panes. This allowed them to exploit the same flexible-mass effect they had observed during the single-paned laminated glass demonstrations.

Figure 9: Laminated Annealed Insulating Glass Unit

7.6. Second-Floor Attack

Firefighters were unable to break the windows on the second floor using a commonly employed standard operating procedure, namely, breaking the glass with the tip of a roof ladder while standing on the ground. Other standard techniques (axe or hooligan used while standing on either a ground or aerial ladder)

The glass of the laminated and filmed panes generally remained attached to the laminate and film, reducing the potential for injuries to firefighters from glass shards falling from upper floor windows.

8. Conclusions and Recommendations

This section presents conclusions and recommendations drawn from the findings presented above and from conversations with the participants and observers at the demonstrations.

8.1. Conclusions

The firefighters were able to enter all of the window mock-ups with conventional firefighting tools such as axes, hooligans' tools, and pike poles. Though conventional tools were equal to the job, updated techniques were required to efficiently break and clear the windows.

Terminology used by firefighters and the building and air-blast communities can vary. It is important to ensure that all parties understand terminology in the same manner.

Emergency firefighter egress may be affected by air-blast resistant windows. A typical technique for emergency exit from an untenable interior atmosphere would be to stay as low to the ground as possible and break a window by swinging a tool (i.e. axe or hooligan) overhead. A concern raised by the firefighters participating in these demonstrations was that this technique may not be possible due to the increased force required to break, vent and clear the air-blast resistant window systems. The implications should be understood by fire departments responding to buildings with air-blast-resistant windows.

Films and lamination tend to hold glass shards together, which can allow firefighters to more easily move the glass away from the operational area and may decrease the likelihood of injuries associated with stepping on glass shards (slip, trip, and fall type injuries). It can also reduce the hazard from falling glass to those working outside the building.

With the tempered glass with daylight film and the laminated glass, the lack of shards remaining in the frame after the break reduces hazards to equipment (hose lines) and personnel during operations.

The addition of a center seam on a four-sided mechanically attached film application did not make a significant difference in entry times.

8.2. Recommendations

- Additional Forcible Entry Tests

Though the window systems tested encompassed a variety of common retrofits, additional widely-used configurations should be tested. These should include:

- Interior fabric and drape systems (this will be included as an addendum to this report)
- Laminated windows with larger bites and structural glazing, conforming with air-blast-resistant window bite requirements (will be included as an addendum to this report)
- Ballistic-resistant glazing
- Emergency egress through air-blast-resistant windows under live fire conditions

- Additional Air-blast Testing

Before a center-seam configuration with a two-sided attached window film is used for an air-blast resistant application, air-blast testing should be performed to ensure that the configuration meets performance requirements.

- Information Exchange

The transfer of information on the implications to forcible entry of air-blast resistant window systems should be made a priority by entities involved in the installation of these window systems. It would be beneficial for the GSA (and other federal or state agencies, as well as private landlords) to routinely inform local fire departments when air-blast-resistant window systems are installed. To assist local fire departments in assessing the demands on their operations placed by air-blast-resistant windows, the following information could be offered:

- A summary paper of this report
- Five-minute video, showing highlights of the demonstrations
- Full-length video, showing all demonstrations

Additional questions or requests for information may be addressed to:

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9. Acknowledgments

These tests could not have been accomplished without the collaboration and cooperation of the GSA, the DHS, the San Jose Fire Department, and the Protective Glazing Council. Thanks also go to GlassLock and Protech for providing materials and support.

10. Limitations

Information presented in this paper and its appendices does not represent an endorsement of any products, tools, or techniques of forcible entry by any of the team of collaborators, including the federal government, the San Jose Fire Department and the Protective Glazing Council.

11. References

1. Hinman, E.E., Durkin, M. E., and Osteraas, J.D., *Preliminary Analysis of Casualties Resulting From the Oklahoma City Bombing*, Report No. FaAA-SF-R-96-12-20, Project No. SF23049, prepared for: The Blast Injuries Study Group, Oklahoma State Department of Health, Oklahoma City, OK, prepared by: Failure Analysis Associates, Inc., Menlo Park, CA, December 20, 1996.
2. GlassLock. "Glass & Glazing." GlassLock website. 14 December 2000. http://www.glasslock.com/glass_types.htm

APPENDIX A

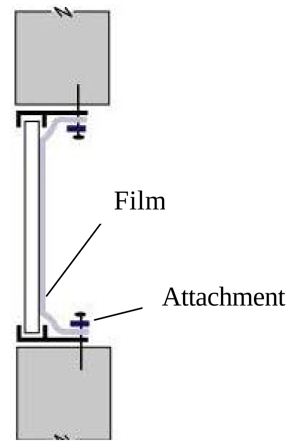
APPENDIX A – TERMINOLOGY

Annealed Glass (AG)

Annealed glass, often referred to as float glass or plate glass, is the most common glass type and is manufactured by pouring molten glass onto a bed of molten tin, the glass solidifies before the tin and is subsequently fed into an annealing lehr where it is slowly cooled to minimize residual stresses.
Annealed glass has a minimum amount of residual surface compression. Because of this, when failure occurs annealed glass typically shatters in large hazardous shards. [2]. Annealed glass is the weakest of the three *glass types* discussed in this report.

Attached Film Application

Retrofit application of *security film* that extends beyond the glass and is fastened to the window frame with either a mechanical attachment device (steel or aluminum *batten*), adhesive tapes, or silicone sealant. At this time, mechanically attached security film is the most common configuration in use. Generally, attached film will give better protection than *daylight film*, if the mullions, frame, and wall are able to withstand the additional loads. Film can be attached on one side (the top), two-sides (either the two vertical or the two horizontal sides), or on all four-sides. The more sides attached to the supporting structure, the more protection provided by the properly designed retrofit.



Mechanically Attached Film

Bite

A window bite is the portion of the window framing system which holds the glass in place. Typical window bites vary from ¼” to ½” and are dry glazed. Window bites for air-blast resistant windows be either *wet glazed* or *dry glazed* and begin at 3/8” if wet glazed and can go up to greater than 1”.

Blast Curtain

Blast curtains, with specially designed fabric and installation methods, self-deploy to catch flying glass and other debris before it projects into the room. Blast curtains are usually used in conjunction with a *daylight film* application.

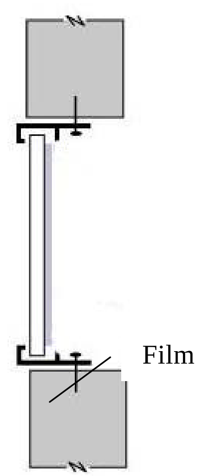
A curtain made of a mesh of high-strength synthetic fibers that is affixed behind a monolithic or daylight-film-retrofitted window to catch glass fragments in the event of an air-blast.

Clearing

Removal of enough glass/film/laminated material from the window frame to allow safe and effective operations through the remaining opening.

Daylight Film Application

Security film which is installed on the vision portion (glass only) of the window system without attachment to the mullions or frames. Hazard to occupants is reduced with this application method, even if the glass/film combination comes



Daylight Film Application

out of the frame. This is primarily due to the glass shards being retained by the film, (few shards available to cause lacerations and penetrating injuries) and the glass/film combination has greater mass and will therefore not penetrate as far into the occupied space. A benefit of this solution is that it does not increase the load transmitted to the mullions and frame.

Dry Glazed
Dry glazing refers to window *bites* which rely on the depth of overlap between the glass and the window frame to keep the glass in place, rather than a *structural silicone sealant*.

Filmed Glass
Filmed glass is untreated glass which has a layer of *security film* installed at the interior surface of the glass.

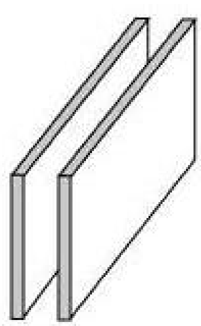
Heat Strengthened Glass (HS)
Heat strengthened glass is produced by heating *annealed glass* to temperatures of approximately 1150 degrees Fahrenheit then rapidly cooling both top and bottom surfaces simultaneously. This locks the surfaces of the glass in a state of high compression and the central core in compensating tension, with neutral layers separating.

Heat strengthened glass lies mid-range between *annealed glass* and *thermally tempered glass* both in overall strength and in breakage patterns.

The break patterns for heat strengthened glass very widely depending on the surface compression and surface quality. On the low end of the range the breakage is similar to *annealed* without the points; on the high end of the range the breakage is difficult to distinguish from *thermally tempered glass*. Because of this, firefighters may not recognize glass as heat strengthened even after breaking it.

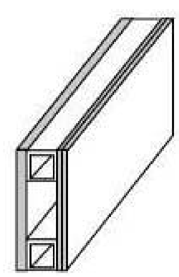
Due to its increased strength, heat strengthened glass may be found in larger window panes or in windows of buildings in high wind areas.

Insulating glass unit (IGU)
IGUs are windows which have two panes of glass separated by an air gap. These window types are generally used for sound or climate control and are found in areas of the United States with more extreme environments or high sound areas such as around airports or rail lines.



Insulating Glass Unit with Monolithic Glass

The glass in IGUs can be any of the normal *glass types* (or a combination of *glass types*) and can be either *monolithic* or *laminated*. In air-blast resistant applications, IGUs will have a *monolithic* outer pane (exterior to the building) and a *laminated* inner pane (interior to the building.)



Insulating Glass Unit with Laminated Glass

Laminated Glass
Laminated glass, often referred to as safety glass, consists of multiple panes of glass bonded together with an interlayer of *polyvinyl butryl (PVB)*. This is similar to the glass found in the windshields of automobiles.

Monolithic Glass
Monolithic glass is a single layer of glass without a laminate interlayer.

Plate Glass
See annealed glass

Polycarbonate
A plastic glazing material with enhanced resistance to ballistics or air-blast effects. This material is not generally used unless windows are serving more than one purpose (i.e. combined air-blast, forced entry and/or ballistics resistance). Polycarbonate windows were not addressed during these demonstrations.

Safety Glass
See *laminated glass*

Security Film
Specially manufactured and tested film which is designed to remain adhered to glass shards in the event of an explosive detonation, thus reducing the potential of penetrating glass shard injuries to building occupants.

Security film is typically a layer of polyester, usually between 7 and 15-mil thick, applied to the interior surface of windows. Security film can be installed in one of two basic configurations: *daylight* applications or *attached* applications.

Structural Silicone Sealant
Structural silicone sealant is a specially designed silicone sealant with high strength and adhesion characteristics. These products are used and tested in air-blast resistant windows to enhance the connection between the window glass and the framing system. Window systems which use structural silicone sealants may have smaller *bites* than those window systems which do not.

Thermally Tempered Glass (TTG)
The manufacturing process for thermally tempered glass is identical to that for *heat-strengthened*, the value for the surface compression is held at a very high quality.

Thermally tempered glass breaks into a multitude of small fragments of cube shape. tempered glass is sometimes known as a safety glazing material.

Untreated Glass
Untreated glass is glass which does not have film or a laminate layer.

Venting
Opening a building releasing toxic gases and smoke to increase visibility and to reduce dangers associated with heat and gas buildup. For the purposes of this report, time to vent was determined by the GSA fire protection representative as the time at which a large enough opening was made in the windows to allow release of smoke and gas.

Wet Glazed
Wet glazing refers to windows which have *bites* augmented by the installation of *structural silicone sealant* at the interior side of the window.

APPENDIX B

APPENDIX B - ATTENDEES

May 28, 2003

Forcible Entry Tests
5/28/2003

Sign In

Name	Company	Email
Holly Stone	Hinman Consulting Engineers	hstone@hce.com
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APPENDIX C

APPENDIX C – DEMONSTRATION PARTICIPANTS

May 28, 2003

Fire Fighter ID	Weight	Company	Years on the Job
FF1	157	E2B	14
FF2	200	E2B	6
FF3	210	E2B	5
FF4	160	E2B	5
FF5	185	E2B	21
FF6	170	GSA	20
FF7	180	T2B	7
FF8	210	T2B	23
FF9	215	T2B	24
FF10	212	T2B	5
FF11	220	T2B	21

APPENDIX D

Test No.	Glass Type	Film/Laminate	Exterior/Interior Attack	Floor	FF	Time of Day	First Break	Vent	Clear	Tools used
1	**1/4" Annealed Glass**	7 mil daylight film	Ext	First	1	920	first swing	10	28	Axe
2	**1/4" Annealed Glass**	7 mil daylight film	Int	First	3	930	first swing	6	39	Axe
3	**1/4" Thermally Tempered Glass**	7 mil daylight film	Ext	First	4	941	2	4	9	Axe
4	**1/4" Thermally Tempered Glass**	7 mil daylight film	Int	First	2	950	1	3	6	Axe
5	**1/4" Annealed Glass**	7 mil 4-sided attached	Ext	First	1	1001	3	5	42	Axe
6	**1/4" Annealed Glass**	7 mil 4-sided attached	Int	First	3	1014	2	5	36	Axe
7	**1/4" Annealed Glass**	7 mil 4-sided attached with vertical seam	Ext	First	4	1026	2	6	26	Axe
8	**1/4" Annealed Glass**	7 mil 4-sided attached with vertical seam	Int	First	2	1037	1	5	31	Axe
9	**1/4" Thermally Tempered Glass**	7 mil 4-sided attached with vertical seam	Ext	First	5	1046	2	3	35	Hooligan
10	**1/4" Thermally Tempered Glass**	7 mil 2 sided attached (vertical) with vertical seam	Int	First	1	1058	1	2	26	Axe

Test No.	Glass Type	Film/Laminate	Exterior/Interior Attack	Floor	FF	Time of Day	First Break	Vent	Clear	Tools used
11	**1/4" Thermally Tempered Glass**	7 mil 2 sided attached (vertical) without vertical seam	Int	First	1	1109	6	15	30	Axe
12	**1/4" Annealed Glass (control)**	none	Ext	First	3	1122	1	1	24	Axe
13				First	Willie	1132	3	3	32	Axe
14	**1/4" Annealed Glass**	0.030" interlayer	Ext	First	5	1145	8	21	31	Hooligan
15	**1/4" Annealed Glass**	0.030" interlayer	Int	First	5	1159	4	6	24	8 lb Axe
16	**1/4" Thermally Tempered Glass**	0.060" interlayer	Int	First	7	1320	5	8	13	Axe
17	**1/4" Thermally Tempered Glass**	0.060" interlayer	Ext	First	9	1332	4	11	17	Axe
18	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.030" interlayer	Ext	First	8	1344	18	18	26	Hooligan
19	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.030" interlayer	Int	First	10	1352	8	18	43	Hooligan
20	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.060" interlayer	Ext	First	11	1405	21	21	24	8 lb Axe

Test No.	Glass Type	Film/Laminate	Exterior/Interior Attack	Floor	FF	Time of Day	First Break	Vent	Clear	Tools used
21	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.060" interlayer	Int	First	11	1413	10	14	26	Hooligan
22	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.090" interlayer	Ext	First	7	1423	2	12	24	Axe
23	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.090" interlayer	Int	First	9	1434	17	22	31	NY Pike Pole
24	**1/4" Annealed Glass**	7 mil daylight film	Ext	Second	8	1450	4	10	71	14' Ground Ladder / Axe
25	**1/4" Thermally Tempered Glass**	7 mil 4-sided attached without center seam	Ext	Second	10	1506	26	26	64	14' Ground Ladder / Axe
26	**1/4" Thermally Tempered Glass**	0.060" interlayer	Ext	Second	7	1520	2	9	22	Aerial Ladder / Axe
27	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.030" interlayer	Ext	Second	11	1532	4	21	32	Aerial Ladder / Axe
28	**1/4, 1/2, 1/4 Annealed Glass IGU**	0.090" interlayer	Ext	Second	9	1544	27	29	35	Aerial Ladder / Crash Axe