INTRODUCTION TO DESIGNING FENESTRATION FOR BLAST MITIGATION
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Learning Objectives

This course will provide an understanding of:

- Blast Hazards
- Blast Mitigation Design
- Blast Resistant Products and Installation
- Blast Mitigation Requirements/Applications
- Acceptable Test Methods
- AAMA 510
- Blast Product/Project Certification
Blast Hazards

- **Primary Fragments**
  - Flying Glass
    - Fly at speeds in excess of 100 ft/second (68 mph)
    - In some cases, speeds may exceed 200 ft/second (136 mph)
  - Flying Building Components

- **Secondary Fragment**
  - Shrapnel
  - Rocks, Dirt, Etc.

- **Structural Collapse/Damage**
Blast Damage
Collateral Damage
Loss of Life, Business Disruption, Property Damage

Financial Institutions, Businesses, Sensitive Buildings, Schools
Understanding a Blast Wave

- Blast is an extreme rapid release of energy which consists of 4 forms
  - Light
  - Sound
  - Heat
  - Shock Wave (Most Deadly)
Shock Wave

- Peak Pressure
  - Occurs instantaneously
  - Dissipates exponentially
- Positive Phase Duration
  - Time the pressure acts positively on an object
- Impulse (very important)
  - Area under pressure-time curve
  - Measure of the total energy acting on an object
- Negative Phase Duration
  - Rush of air to fill the void behind the blast wave
  - Pulls the product and fragments to the exterior
Shock Wave

Typical Blast Wave
Incident (Side-on) Overpressure

- Peak Overpressure $P$ measured in psi
- Impulse $I$ measured in psi\cdot msec
- Positive Phase Duration $t_d$
- Negative Phase Duration
- Rebound Phase

Pressure (psi)
(+ psi) Ambient Atmospheric Pressure
(- psi)

Time (msec)
High Pressure- Low Impulse

- ¼” Lami w/0.060” PVB
- P = 8.9 psi
- I = 42 psi-msec
- ¼” screws at four jamb corners – screws bending - tearing in frame wall at connections pushing limits of ASTM F 2248
- Minimal Hazard
Low Pressure-High Impulse

- ¼” Lami w/ 0.060” PVB
- P = 7.7 psi
- l = 71 psi-msec
- ¼” screws at four jamb corners – failed in bending / shear
- HAZL rupture threshold
- High Hazard – Blowout, frame hit wall, folded in ½, glazing retained, no tears in PVB
Nature of a Blast
Charge Weight and Standoff

- **Charge Weight**
  - Amount of explosives used (*TNT equivalent*)

- **Standoff Distance**
  - Distance from *point of detonation*

- **How They Relate**
  - As charge weight increases, peak pressure increases
  - Pressure decreases *exponentially* with standoff distance
  - As standoff distance increases, peak pressure decreases, but duration typically increases
  - Both are used to determine Peak Overload
Pressure and Distance

<table>
<thead>
<tr>
<th>Range (ft)</th>
<th>Shock Velocity (ft/msec)</th>
<th>Time of Arrival (msec)</th>
<th>Pressure (psi)</th>
<th>Impulse (psi-msec)</th>
<th>Load Duration (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>1.25</td>
<td>18.26</td>
<td>10.11</td>
<td>24.33</td>
<td>4.81</td>
</tr>
<tr>
<td>43</td>
<td>1.21</td>
<td>26.41</td>
<td>6.5</td>
<td>18.27</td>
<td>5.62</td>
</tr>
<tr>
<td>53</td>
<td>1.19</td>
<td>34.72</td>
<td>4.74</td>
<td>14.62</td>
<td>6.17</td>
</tr>
<tr>
<td>63</td>
<td>1.17</td>
<td>43.13</td>
<td>3.7</td>
<td>12.18</td>
<td>6.57</td>
</tr>
<tr>
<td>73</td>
<td>1.16</td>
<td>51.62</td>
<td>3.03</td>
<td>10.43</td>
<td>6.89</td>
</tr>
<tr>
<td>82</td>
<td>1.16</td>
<td>59.35</td>
<td>2.59</td>
<td>9.23</td>
<td>7.13</td>
</tr>
</tbody>
</table>

![Graph 1: Pressure vs. Range](image1)

![Graph 2: Impulse vs. Range](image2)
Blast Wave Interaction

- Blast waves act on a structure for a short duration
  - Blast duration of a large explosive device is 41 milliseconds – roughly 1/8 the time it takes for an eye to blink
- Results typically vary for differing materials and construction, according to:
  - Material flexibility
  - Material ductility
  - Material strength
Designing Fenestration to Resist Blast Hazards

- Blast Mitigation Solution
- Anchor System
- Installation
- Window System
- Building Preparation
- Threat Assessment

Threat Assessment → Building Preparation → Anchor System → Installation → Blast Mitigation Solution → Window System → Threat Assessment
Threat Assessment

- Threats: suitcase, backpack, small car, large truck, semi-truck, etc.
- The most effective protection is to keep the explosives away from the building
  - Bollards
  - Parking control
  - Traffic control
  - Parking lot locations
  - Physical security/surveillance
- Impact of the threat on the building & personnel
Identifying a Threat Level

- Height Above Ground (Lower Pressure)

- Structure

- TNT load equivalent
- Standoff distance
- Height of glazing

W – Pounds
Building Preparation

US Embassy, Nicosia, Cyprus

Typical new design with perimeter control and standoff distance
A building cannot be designed to be blast or ballistic proof. The key is to limit the damage to an acceptable level.

Question is how extensive and how widespread is the localized or “acceptable” damage.

Good design is always a compromise between acceptable damage and product cost.

Products can be designed to reflect (rigid) or absorb (flexible) energy.
4 criteria for blast mitigating fenestration systems

- Limitation of flying shards
- Glass retention
- Frame support
- Wall Integrity

Anchors must be evaluated for each product application and wall substrate
Potential Result without Blast Product
<table>
<thead>
<tr>
<th>24</th>
<th>Glazing Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Laminated Glass</td>
</tr>
<tr>
<td></td>
<td>Window Film</td>
</tr>
<tr>
<td></td>
<td>Polycarbonate</td>
</tr>
<tr>
<td></td>
<td>Insulating Glass Unit</td>
</tr>
</tbody>
</table>
Laminated Glass

- DOD requires a 6mm lamination on the interior
- Laminated glass is available with many different interlayers and configurations
  - Laminated/Air Space/Laminated
    - Best, but typically cost prohibitive
  - Annealed or Tempered/Air Space/Laminated
    - More cost effective
Window Films

- Typically used for retrofit applications.
- Film is applied to inside of glass
- Quick fix for U.S. Embassies after 9/11
- Unknown life span
- Possible UV caused ‘yellowing’
- Glass may disengage from frame if not mechanically fastened
- Windows may disengage from building
Polycarbonate

- Too flexible for larger lites
- Requires impractical glazing bites
- Whole polycarbonate lite may disengage
- The lites may need to be extraordinarily thick
- Not always available in IG units
Insulating Glass (IG)

- IG units where both lites are laminated provide the best protection and shard retention
  - May be cost prohibitive
- Typically, use of a single laminated lite in an IG unit is more cost effective
  - Best shard retention is achieved when the laminated lite is on the side away from the blast site (interior)
  - The other lite is typically annealed, heat strengthened or fully tempered
Anchor and Trim System

- Must be able to resist blast loading
- Must be evaluated for type, size, spacing and embedments
- Must maintain edge clearances
- Must attach to building structural substrates and transfer the load
- Failure can compromise effective blast mitigating windows
- Engineering review recommended
Example of Anchor System

- Retrofit masonry reinforcement anchor usually for higher pressures
Pin Anchor

Epoxy/Grout Anchor

Wedge/Expansion Anchor

Wedge Bolt Screw Anchor

Coated Anchor
Installation

- Install products in strict accordance with approved shop drawings
- Installation should be reviewed/certified by an independent person/agency
- Consider hiring trained and experienced installers
Structural silicone sealant must be installed per the manufacturer’s recommendations and/or testing.
Installation
Blast Mitigation Considerations

- Structural integrity of frame
- Glazing bite
- Structural sealant width and depth
- Anchors
- Structural integrity of building substrate
- Thickness of laminated glass
- Retention of glazing beads and trim
- Certification per AAMA 510
- Mock-up testing and engineering
Potential Result with Blast Product

1/500 CENTER 500FPS

03 04-30-03 PLAY 000063
00001260sec

FWD30
Acceptable Test Methods

- **Open Arena**
  - Detonation of an actual explosive device is required
  - Specimens are mounted in individual chambers
  - Allows for testing of multiple windows at one time

- **Shock Tube**
  - High pressure air pulses are released through a pipe or tube directed at the test specimen
  - Specimens are sequentially tested in a reusable test frame
  - Allows for testing of one window at a time
Open Arena Testing
Open Arena Testing

- **Advantages**
  - Charge weight and standoff requirements are explicitly replicated
  - Large specimens can be tested
  - Multiple blast levels and multiple specimens can be tested with one shot

- **Disadvantages**
  - Scheduling issues with weather, permits and availability of chambers
  - Remote locations can increase construction and installation costs
Shock Tube Testing

Courtesy of Baker Engineering and Risk, San Antonio, TX
Shock Tube Testing

- Advantages
  - Controlled, indoor laboratory environment
  - Minimal chamber expense as test frame and witness chamber is re-used for each test.
  - Shock Tube can be calibrated thereby producing repeatable tests

- Disadvantage
  - Limited specimen size
| 42 | Blast Mitigation Requirements and Applications |
Current Guideline Specifications

1. **ASTM F 1642**, Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings
3. **UFC 4-010-01**, Minimum Antiterrorism Standards for Buildings
5. **ASTM F 2248**, Standard Practice for Specifying an Equivalent 3-Second Duration Design Loading for Blast Resistant Glazing Fabricated with Laminated Glass
- Test standard to evaluate the hazards from window systems under blast loading
- Provides a rating on how well the window performed

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
<th>Glazing Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glass not cracked, fully survived and/or retained by frame and no glass fragments either inside or outside the structure.</td>
<td>None.</td>
</tr>
<tr>
<td>2</td>
<td>Glass may be cracked but is retained in the frame.</td>
<td>No significant fragments. Dusting or very small fragments near sill or on floor acceptable.</td>
</tr>
<tr>
<td>3a</td>
<td>Glass failed and not fully retained in frame.</td>
<td>Yes – Lands on floor no more than 3.3 feet from window.</td>
</tr>
<tr>
<td>3b</td>
<td>Glass failed and not fully retained in frame.</td>
<td>Yes – Lands on floor no more than 10 feet from window.</td>
</tr>
<tr>
<td>4</td>
<td>Glass failed and not fully retained in frame.</td>
<td>Yes – Lands on floor more than 10 feet from window and impacts a vertical surface located no more than 10 feet behind the window no higher than 2 feet above the floor level.</td>
</tr>
<tr>
<td>5</td>
<td>Glass fails catastrophically.</td>
<td>Yes – Lands on floor more than 10 feet from window and impacts a vertical surfaced located no more than 10 feet behind the window above a height of 2 feet.</td>
</tr>
</tbody>
</table>
GSA/ISC Hazard Classification

Injury Hazard Classification

Interagency Security Committee = ISC
# GSA Protection Levels

<table>
<thead>
<tr>
<th>Type</th>
<th>Occupants</th>
<th>Square Feet</th>
<th>Tenants</th>
<th>Maximum Over-pressure</th>
<th>Maximum Impulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&lt;10</td>
<td>&lt;25K</td>
<td>Recruiting Office</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>&lt;150</td>
<td>&lt;80K</td>
<td>Social Sec. Admin.</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>&lt;450</td>
<td>&lt;150K</td>
<td>Law Enforcement</td>
<td>4 psi</td>
<td>30 psi-msec</td>
</tr>
<tr>
<td>D</td>
<td>&gt;450</td>
<td>&gt;150K</td>
<td>Courts, Justice</td>
<td>10 psi</td>
<td>90 psi-msec</td>
</tr>
<tr>
<td>E</td>
<td>&gt;450</td>
<td>&gt;150K</td>
<td>Pentagon, CIA</td>
<td>Classified</td>
<td>Classified</td>
</tr>
</tbody>
</table>
DOD’s Minimum Antiterrorism Standards

- Purpose is to minimize flying glass hazards
- Applies to windows, skylights, and glazed doors
- Incorporates entire building and environment
- Applies to new, existing, and leased buildings
Applicable to all projects after 2004 (Base Commander Option)

Frame design per ASTM F 2248, ASTM E 1300 and UFC 040-01

No reference to 7 kPa (1 psi) load

Minimum glass size - ¼” Laminated (0.030)

Deflection at L/160

Minimum glass bite 3/8” with structural glazing or 1” bite

Glass pressure per ASTM 2248
Word “minimum” standoff deleted
Connection calculations
Window pressures per ASTM F 2248, 3 second response
Deflection limited to L/160 for mullions and rails
Minimum glazing bite is ½”
Minimum laminated lite is ¼” with 0.30 interlayer
Residential – Groups of 13 houses or more
Based on charge weight and standoff distance
UFC 4-010-01 Oct. 2003 Criteria

- Must be structurally glazed if bite is ≤3/8” otherwise the product must have a minimum 1” glazing bite
- Standard for windows, skylights, and glazed doors
  - Applies to products with a vision area up to 32 ft²
- Frame member design
  - Equivalent static pressure of 1 psi, maximum deflection L/60
  - 1 psi (7 kPa) static equivalent pressure product will not meet this criteria
Connection Design

- Connections including glazing stop and hardware connections must meet:
  - 10.8 psi (75 kPa) for vision area less than 1-square meter (10.8 ft²)
  - and 4.4 psi (30 kPa) for vision areas between 10.8 ft² (1 m²) to 32 ft² (3 m²)

Glazing Design

- ¼” minimum laminated required
#1, #2 and #3 must meet the blast design criteria
Renovation Issues for Blast Mitigation
(New Construction vs. Renovation)

- Fenestration can be designed for retrofit applications
- Fenestration can be designed for new construction
- Fenestration can be historically replicated
- Applied films, per UFC 4-010-01, January 2007
  - Not allowed in government-owned buildings
  - Restriction does not apply to government-leased buildings
The design criteria and test requirements for higher pressure windows are much different but the procedures and cautions are the same.

- UFC uses low and high pressures as defined by charge weight and standoff distance
- GSA uses medium pressures at 4 psi/30 psi-msec
- DOJ and DOS usually specify higher pressures
Procedures for the evaluation of hazards of glazing or glazing systems compared to specific airblast loadings

Provides a rating system to evaluate the hazards of the window for a specified blast loading

Testing Requirements
- Testing Facilities
- Testing Layout
- Reporting Processes
- Blast Level Scaling
# ASTM F 1642 Test Method

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No break</td>
<td>Glazing does not fracture and no damage to the framing system</td>
</tr>
<tr>
<td>2</td>
<td>No hazard</td>
<td>Glazing fractures but is fully retained in the frame</td>
</tr>
<tr>
<td>3a</td>
<td>Minimum hazard</td>
<td>Glazing fractures and is retained in the frame, minimum fragments fall within 1 meter of the original vertical plane</td>
</tr>
<tr>
<td>3b</td>
<td>Very Low Hazard</td>
<td>Glazing fractures and is mostly retained in the frame, fragments fall within 1 meter of the original vertical plane</td>
</tr>
<tr>
<td>4</td>
<td>Low Hazard</td>
<td>Glazing fractures and fragments fall within 1 meter to 3 meters of the original vertical plane</td>
</tr>
<tr>
<td>5</td>
<td>High Hazard</td>
<td>Glazing fails catastrophically</td>
</tr>
</tbody>
</table>
ASTM Hazard Classification

Injury Hazard Classification

Interagency Security Committee = ISC
Method to specify an equivalent 3-second design loading suitable to use with practice E 1300 to select the thickness and type of blast resistant glazing fabricated with laminated glass.

Window framing system should attach mechanically to the building’s structural framing system with fasteners designed to be blast resistant.

Assumes framing members will restrict deflections of glass edges to L/160 under the 3-second duration design loading.
ASTM E 1300

- Used to determine the glass thickness and bite based on the blast load
- CD is available from ASTM for this calculation
Putting It All Together
AAMA 510-06

- Definitions
- Specifier Instructions
- Performance Conditions
- Standard Test Sizes (varies)
- Project-Specific Certification
- Product-Specific Certification
Provides a uniform rating system
- Defines test report requirements
- Serves as the basis for both types of certification
  - Product-specific
  - Project-specific
| 63 | Blast Product and Project Certification |
Two Certification Program Options

- Product Specific Certification
- Project specific Certification

The blast certification program administrator is Architectural Testing, Inc.
www.archtest.com
Two Certification Program Options

- **Product Specific Certification**
  - Licensees certify that their products meet the requirements of one or more performance specifications.
Two Certification Program Options

- **Project Specific Certification**
  - Licensees certify that their products meet the requirements of a specific project
Product-Specific Certification Option

- Products may be certified to:
  - ASTM F 1642
  - GSA TS01
  - AAMA 510
  - UFC 4-010

Note: Other performance specifications may be used for product certification at the request of the participating Licensee.
The certification process includes:

- Verification that the participating product satisfies all requirements of the referenced specification as tested by a qualified independent laboratory
- Third Party Review and approval of the Licensee’s quality assurance program
- Manufacturing site visits to verify ongoing quality control and production are consistent with verified test reports and approved quality manual
The project-specific certification process includes:

- Verification that the product satisfies all performance requirements of the referenced project specification as tested by a qualified independent laboratory
- Verification that the installation details comply with the reference project requirements
- Verification at the manufacturing plant that the product being produced for the project complies with the verified product details
- Verification at the project site that the actual installation details comply with the verified installation details
Project-Specific Certification Option

- Provides the owner and architect with independent verification that certified fenestration products comply with the project specifications.
Moving Forward
Overall Product Performance and Certification

- Radio Frequency Interference Attenuation (Task Group)
- Forced Entry Resistance (Task Group)
- These are under review by AAMA

**Under Discussion:**
- Retrofit
- Collateral Damage

**In Development:**
- Ballistics
- RFI Attenuation
- Forced Entry

**Available:**
- Acoustical Blast
- Blast Installation
- Hurricane (Impact)
- Seismic
- Commercial Installation
Resources

- www.aamanet.org
- www.atf.treas.gov
- www.defenselink.mil
- www.gsa.gov
- www.protectiveoglazing.org
- www.umr.edu
Seminar Evaluation

Please take a moment to complete the evaluation form.

Thank You.

Questions?