LEARNING OBJECTIVES

After reading this article, you should be able to:

- Discuss blast mitigation application protocols that help building teams successfully create safer building and protect more occupants.
- List the key metrics, terms and variables required in specifications for blast-mitigating windows and doors
- Describe the requirements of federal building agencies for blast-protective openings, including for the GSA, the Department of State, and the Department of Defense.
- Compare the performance considerations for blast hazard mitigating technologies including window films, polycarbonate, laminated glass, and hardware including high-performance engineered anchoring.

Blast Hazard Mitigation: Building Openingsfor Greater Safety and Security

By C.C. Sullivan

Increasingly, explosive blast concerns are driving the design of sites, structures, façades and glazed openings for today's commercial, institutional and industrial facilities to protect. Driven by risk assessment incorporating potential injury and asset loss related to security breaches and varied event threats, building teams are going beyond perimeter security and standoff requirements to advance architectural hardening techniques that address both occupant preferences and long-term owner liability concerns.

"Physical security measures to address an explosive threat considers the establishment of a protected perimeter, the prevention of progressive collapse, the design of a debris-mitigating façade, the isolation of internal explosive threats that may evade detection through the screening stations or may enter the public spaces prior to screening and the protection of the emergency evacuation, rescue and recovery systems," according to the *Whole Building Design Guide*.

"The protective measures are attained through a balanced design where building structural components are both strong and functional, absorbing and reflecting the loads," adds Tom Haines, an executive with blast mitigation systems manufacturer, Norshield Security Products."Also essential is careful consideration of properly locating the building on a safely arranged site, and designing suitable layouts of inhabited and operating spaces."

According to the Federal Emergency Management Agency (FEMA), "Mitigation measures that may be applied to building elements, include architectural, structural, and building envelope systems." The agency guidance notes that in addition to catastrophic collapse, which causes the majority of fatalities in blasts – as at the Oklahoma City bombing in 1995, where 87% percent of the building occupants killedwere occupying the collapsed portion of the Murrah Federal Building – many significant injuries "are caused by flying glass fragments and debris from walls, ceilings, and non-structural features." To address these challenges, a number of building products and systems have been developed with performative qualities mitigating blast hazards, including:

- Aluminum and steel windows and door for ballistic, blast, and forced entry protection.
- Aluminum curtain wall and entrance systems for blast and ballistic applications.
- Teller windows, roof hatches, guard booth enclosures, and similar security specialties.

In addition, custom-produced systems of varied sizes and complexity are commonly designed and built for specific threat hazards. To understand how all these assemblies are specified, building teams must consider first the nature of blast hazards and related opportunities in blast mitigation. Teams then apply that understanding to the selection of blast-resistant products and requirements fortheir installation. The general requirements of blast mitigation and application protocols help building teams successfully create safer building and protect more occupants.

Understanding Blast Hazards

The forces of blasts are significant. Flying glass, for example, can achieve speeds from 100 feet per second (68 mph) and up to 200 ft./sec. (136 mph) and faster, as seen in studies reviewed by the Centers for Disease Control (CDC), for example. While not the only hazard, flying glass should treated as the ***primary fragment*** and main concern for building operations and safety during a blast impact. A second primary concern is blast pressure, which potentially results in as many injuries or deaths as flying glass shards.Others include:

- Secondary fragment (shrapnel, rocks, dirt and the like).
- Structural collapse and damage.

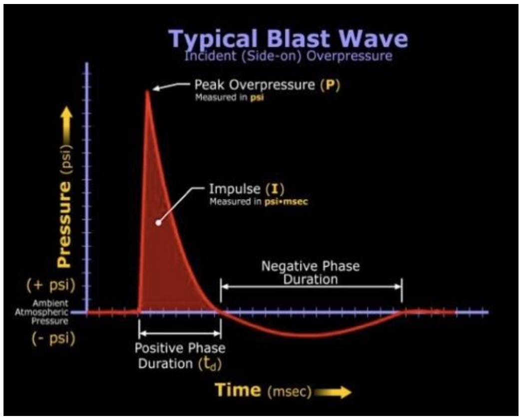
Note that these three effects of concern often cause additional dispersal of the primary fragment: glass.

Determining variables in how much fragment, structural damage and pressure are produced arethe charge load size along with the ***standoff distance***, or the gap between the target – which may be a building, bridge, entry area or similar — and the explosive material. The relationship between standoff distance and pressure is significant (see Table 1): The pressure of a blast from 10 feet can be 1,000 times the ***pressure*** (or load) of a blast from 200 feet away. Also more intense are associated fragment velocities and ***impulse*** loads, which FEMA describes as "a measure of the energy from an explosion imparted to a building." Impulse gives overpressure load and time, expressed in pounds per square inch (PSI) andmilliseconds, or PSI-msec. In broad terms, the impulse can be calculated approximately by multiplying the blast pressure by the duration of the blast's force on the building or opening, divided by two.

Standoff Distance (ft)	Velocity (ft/msec)	Time of Arrival (msec)	Pressure (PSI)	Impulse (PSI-msec)	Duration (msec)
10	5.76	1.04	3285.61	1067.39	0.65
30	2.08	7.66	160.02	249.12	3.11
50	1.50	19.26	37.85	135.78	7.18
70	1.33	33.59	17.32	92.69	10.70
90	1.26	49.19	10.62	70.21	13.23
110	1.22	65.38	7.52	56.46	15.01
130	1.20	81.87	5.78	47.19	16.33
150	1.19	98.53	4.67	40.53	17.35

The pressure wave created by the blast has a positive phase as well as a negative phase, which are studied in blast testing.Blasts are characterized by their peak overpressure and impulse, and some blasts have higher pressures and lower impulse, while others have lower pressures and higher impulse. All of this depends on the standoff distance, charge load size, and the type of explosive material.

Lower pressure, higher impulse blasts can cause more forceful damage in some cases. A laboratory comparison shows the effects of two different blasts applied to a test section of 1⁄4" laminated glass with a protective, polyvinyl butyral (PVB) interlayer measuring 0.060 inches, fixed to a frame by fasteners.A test with high pressureand low impulse is shown to present a relatively more minimal in creating a hazard: the pressure recorded is 8.9 PSI and the impulse is 42 PSI-msec. Steel self-tapping screws used around the opening perimeter remain in place, while fasteners are seen to bend and pull out from the window frame.



A lower-pressure blast with a higher impulse, on the other hand, can cause relatively more building enclosure damage. The same PVB enhanced ¼-inch laminated glass and frame assembly, subject to a blast pressure of 7.7 PSI and impulse of 71 PSI-msec, experiences full failure of the self-tapping perimeter fasteners as well as, most notably, failure of the metal frame. The glazing, however, is retained, helping to reduce primary (glass) fragment projectiles.

Tests of this nature are conducted by various independent and military and government laboratories. One of the test protocols employs a *shock tube*, a mechanical instrument that replicates blast waves and directs them toward the subject building assembly. A second test method is called *open-air area blast testing*.In addition to approximatingactual explosions and their effects, these simulations also provide data on maximum pressures withstood by the assemblies, allowing engineers to calculate their design and application parameters.

Complete Blast Specifications

How do experienced building teams achieve these and other desirable outcomes even in the face of higher blast impulse and pressure? In order to properly specify architectural security and life-safety assemblies, building teams need to know several variables in blast mitigation performance. Among these critical types of information are the following, which allow engineers on the building team determine peak pressure and impulse load:

- Blast size, known as ***charge weight***.This is given in kilograms or pounds. For certain military applications including Department of Defense (DoD) Unified Facilities Criteria (UFC),two categories may be used to describe size or weight: Explosive Weight 1 for larger charges, as may be carried by a vehicle, and Explosive Weight 2, which may be moved by or attached to a person.
- ***Standoff distance***, or span from explosion to building opening. Measured in meters or feet, standoff distances vary indirectly with force or pressure applied to the opening. For a given charge load, the smaller the distance, the greater the force.

In addition, design values for peak pressure and impulse (or duration, or both) are essential for proper façade assembly specification, so building teams should have the design ***pressure*** in PSI or kilopascals (kPa) andthe specified duration in milliseconds. These are typically cited in reference specifications or determined by project engineers and manufacturers based on the size of the assumed explosive and predicted standoff distances. With the pressure and duration, the project specifiers also can determine the design ***impulse*** value.

Last, for Department of Defense DepartmentUFC military blast projects, the team should have the ***static equivalent load***, given in pounds per square foot (PSF or psf).This measure is a dynamic blast load converted to a 3-second wind gust or static load, providing a way to simulate the highly dynamic effects of blast loading while simplifying the loading analysis.

Specifying for Government Buildings

For the U.S. General Services Administration (GSA), project specifications determining blast performance are given for a number of facility types, including all new and existing federal buildings. Similarly, the Department of Defense initiated the UFC, Unified Facilities Criteria Program, to unify all technical criteria – known as UFCs – and guide specifications, called UFGS, according to *Whole Building Design Guide*. These are used in the “planning, design, construction, sustainment, restoration, and modernization criteria” applied to various DoD agencies, military departments, and field activities.

Last, the U.S. Department of State also provides for required blast criteria for buildings such as the embassies and consulates contracted through its Bureauof Overseas

Building Operations (OBO), tasked to provide safe, secure, functional, and resilient facilities that represent the U.S. government to host nations.

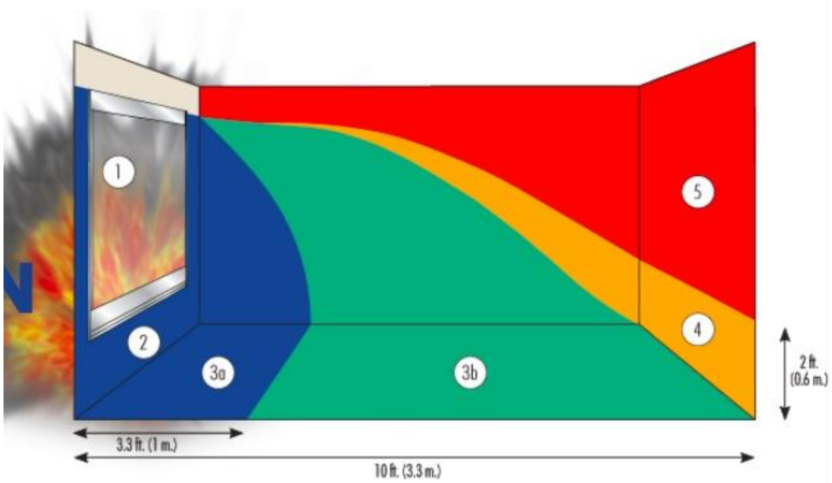
Due to the nature of their operations, these unique public-sector entities routinely plan for blast hazards and have explicit, required blast identification types for conformance by building teams when selecting and designing opening types. In particular:

GSA Federal Building Projects

--Distinguish four blast levels: A, B, C, and D.

--Includea new standard stating pressure and impulse or duration.

For its office buildings, justice and military facilities and presidential libraries, among others, the GSA Inter-Agency Security Committee (GSA-ISC) specification, *Security Design Criteria for New Federal Office Buildings or Major Modernizations*, often applies for blast hazard mitigation.The GSA's most basic blast criteria, *Level A*, effectively means that no protection is needed and that standard construction is acceptable or preferred. *Level B*, on the other hand, requires the use of laminated glass, applied film, or tempered glass in its building projects — which could be required to address a wind zone consideration, for example, rather than security issue.



For the GSA's military structures, the building team's engineers and blast or securityconsultants typically must calculate peak pressure, impulse or duration, and hazard and protection criteria conformance. Design parameters for *Level C* typically are specified for a 4 PSI pressure (27.6 kPa) at an impulse load of 28 PSI-msec (193.1 kPa.msec) or 14 msec duration. *Level D* is a more rigorous standard of 10 PSI @ 90 PSI-msec (68.9 kPa and 613.6 kPa.msec, respectively) or 19.8 msec.In addition to these levels A-D, there is also a newer standard provided by the GSA that is more building specific.

In addition to these criteria, the GSA's own ***Hazard Condition Ratings*** are based on a testing standard for dangers to building occupants based on the final locations of glass fragments caused by a blast. (See Figure 2.) In the GSA/ISC clarification, each numbered zone corresponds to a GSA hazard definition: Condition 1, for example, means noglass breakage occurred, and Condition 2 describes a possible breakage but that the glazing has remained in the opening's frame. Condition 3a applies to glass fragments and frame components that have entered the occupied space by less than 3.3 feet, while Condition 3b is for fragments and frame components that have entered the occupied space between 3.3 feet to 10 feetfrom the window. In Condition 4, the fragments have entered the space as high as 2 feet at a distance of 10 feet, and Condition 5 is described as glass that breaks and produces "potentially lethal shards," according to the GSA/ISC, by entering the occupied space above the 2 foot mark at a distance of 10 feet or more.

The GSA also requires a complete system so that safety is not relying on one component but rather the entire window system, calling for "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."

UFC Military

--Static load in PSF pressure and impulse or duration.

Between 2003 and 2018, the DoD's UFC has updated its standard UFC 4-020-01, *Security Engineering Facilities Planning Manual,* to improve its established "minimum engineering standards that incorporate antiterrorism (AT)-based mitigating measures where no identified threat or level of protection has been determined." The standard applies to new and existing construction as well as temporary or expeditionary projects, and gives building teams a basis for appropriate engineering to "develop appropriate, effective, unobtrusive, and economical protective designs" to the levels needed for building designs and to allow commanders to make proper resource allocation decisions.

For projects meeting the2003 revision of UFC 4-010-01,glazed openings generally have frames designed to a 1 PSI load and connection loads tested to 10.8 PSI minimum for glazing panels under 10.8 square feet or 4.4 PSI minimum for glazing panels between 10.8 and 32.0 square feet. In the 2007 edition of UFC 4-010-01, the maximum blast capacities for openings changed: For charge weights given by UFC and indicated as WI or WII, standoff distances were required to be33 feet, 82 feet, or 148 feet. In terms of structural performance, the 2007 edition also requires design loads for glazing systems to have a maximum allowable deflection of L/160 of the clear span.

More recently, a 2012/2013 revision of the UFC requirements provided that standoff distance would vary depending on building construction, and required design loads with an allowed deflection of L/60 of clear span. Then, in 2018, a revision of UFC 4-010-01 created some confusion on blast requirements, with varied standoff distances depending on building construction. It allows, for example, that the standard may only require laminated glass with no calculations, while for higher-level operations, buildings may still need blast requirements. The allowed deflection remained at L/60, yet otherwise the new version left some perplexed building teams struggling to understand the blast resistance levels for their military projects.

Department of State (within the United States)

--*State Department has its own blast standard.*

--*Agency may revert to the GSA standard on projets within the United States*

The U.S. Department of State Department has required blast criteria for buildings under its jurisdiction, though there is a chance the Department will revert to the GSA standards used in the past. Notable changes to the agency's standard include its recent Revision H, for large blast loads, which is classified.The State Department also requires a "Forced Entry" level specification, SD-STD-01.01G,which designs for a "heavy hand-tool attack" and is much more substantial than those set forth in ASTM's standards F1233, F1915 and the like, or in HP White's TP-0500.03 or standards used by Walker-McGough-Foltz & Lyerla, known as WMFL.

Last, the State Department also includes a Ballistic Attack requirement based on various NATO assault rifle rounds. This provides for a ballistically tested product that also has a forced entry rating.

Glazing Selection and Specification

To address these and otherblast performance standards and to provide for optimal protection of occupants and building spaces, buildings teams should consider a number of glazing options and window and door designs. These include window films, polycarbonate, acrylics, laminated glass, and insulated glass units, or IGUs. In addition, a number of engineered anchoring solutions help create safer openings

-- ***Window Film***. Typically used for retrofit applications, window films may provide for a quick fix or a short-term solution in some cases. One notable issue: Their performance is unknown when applied to non-blast-rated windows. In general, for these approaches, the film is applied to the inside of glass panels, and mechanical attachments are specified so the glass is less likely to disengage from frame. Window film testing has not provided conclusive evidence of their life span; chemicals and cleaners can damge the films, and ultraviolet (UV) light can, in some cases, cause*yellowing*, too. For a number of reasons, including because glass and window assemblies may disengage from opening conditions, window films are not allowed on certain project types, including military blast applications.

-- ***Polycarbonate***. A common architectural material, polycarbonate is relatively expensive and tends to be excessively flexible for use in larger window openings, causing possible disengagement under blast loads. Ideally, polycarbonate panels must be laminated with harder material for rigidity, which may make them excessively thick or necessitate impractical glazing bites, or both. As another practical matter, polycarbonate may not be available in IGUs, due to the materials incompatibility with sealing. Polycarbonate is permeable by air and moisture, which may cause fogging within the air seal between lights, and it can also exhibit yellowing resulting from UV exposure. It can be scratched relatively easily and may experience damage such as crazing from chemicals such as those in window cleaning fluids.

-- ***Acrylics***. To use acrylics in glazing applications, building teams must address similar challenges for this relatively expensive clear panel material including scratching, UV yellowing and damage,and crazing caused by chemicals and cleaners. In general, experts consider acrylic panels to be too brittle for blast applications, as they tend to shatter under many blast conditions. Very thick panels are required in order to survive blast loads, and as with polycarbonate, sealing IGUs is not possible. Limited availability is another challenge.

--***Laminated Glass***. Conversely, laminated glazing is widely and globally available, with an extensive variety of interlayers and configurations. It is highly effective for lower-level interior security applications and can be designed to meet a variety of combined threats and attacks, including hurricane projectile impacts, acoustic performance, ballistics ratings, forced entry threats and blast loads. As for the downsides, laminated glass can be an be damaged somewhat easily and the panels can be heavy depending on thicknesses specified.

--***Insulated Laminated Glass***. Similarly, insulated laminated glazings are available readily in practically any location around the world. Its advantages and drawbacks are similar to those for laminated glass, noted above.

--***Glass-Clad Polycarbonate***. Much lighter than laminated glass panels, glass-clad polycarbonate glazings can be engineered with various amounts of polycarbonate to achieve a desired weight. Available with many different interlayers, coatings and combinations, glass-clad polycarbonates work well for IGUs and can meet varied blast, forced-entry and hurricane needs. Glass-clad polycarbonate is widely seen by experts, law enforcement and other public agencies as an exceptionally effective transparent glazing technology for higher-level security applications. That said, the panels are not widely available and have longer lead times than glass. The panels can tend to be heavy, and they can be damaged relatively easily.

--***Engineered Anchoring***. Considered in various grades includingstandard and high-performance, engineered anchoring systems are specified and manufactured based on the required sizing, spacing and hardware types. They are designed by professional engineers as required for the project applications, and may include: bolts for anchor channels, Tek screws, cast-in-place anchor channels, concrete screw anchors, adhesive anchors, and wedge bolts.

Overall, glazing selections and engineered anchoring systems created for blast hazard mitigation must be carefully evaluated not only individually but also as a part of a properly designed system of protection. In addition to glazing and anchoring components, building teams carefully review the overall system design including supporting wall designs, the framing assemblies for fenestration, and all embedded components used for anchorage, including bolts and fasteners.

Just as proper system design is critical to performance, the building team's specifications and product choices are the foundation of effective blast hazard mitigation in every facility. Blast calculations or testing – or both – are vital elements of those building design choices and system specifications, ensuring every given component contributes to the overall security and safety methodology. The best way to ensure safety for personnel, facilities and occupancies is to engage knowledgeable consultants and suppliers as part of the architecture, engineering and construction delivery process. Blast hazards are serious, and a knowledgeable team provides the gateway to mitigation.