
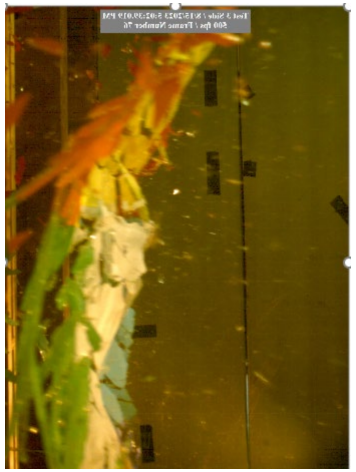


Low Pressure Window Breakage and Human Vulnerability Testing

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Outline

- Background
- Defining Work Areas and Purpose
- Window Breakage Testing for Hazard Characterization
  - Shock Tube Testing & Apparatus
  - Shard Size Distribution
  - Shard Velocity Distribution
- Testing Human Vulnerability from Shard Impacts
- General Findings and Project Status

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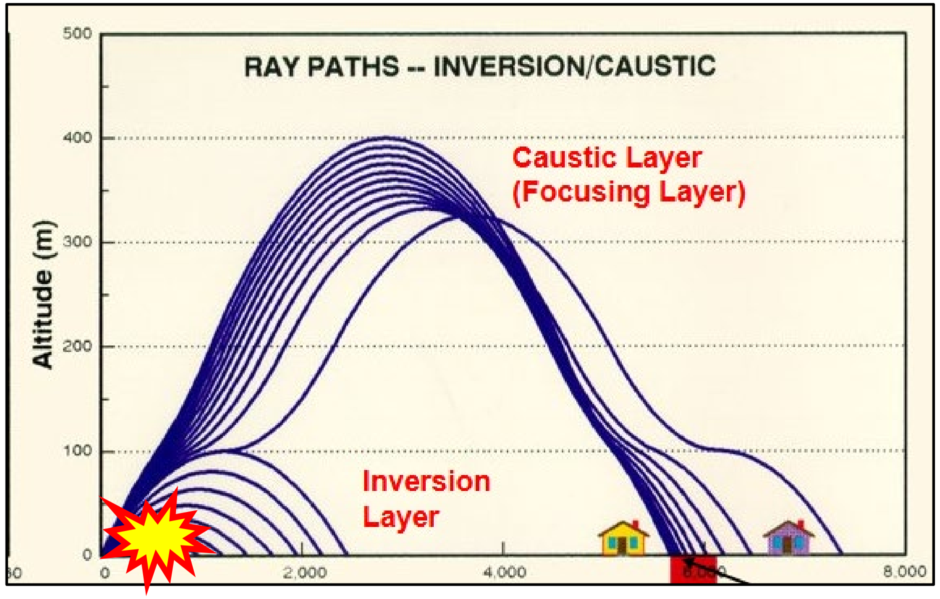
Background

- Distant Focusing Overpressure (DFO) is a phenomena that can occur in which air blast waves generated from a large explosion can return to the ground and focus at large distances
  - Near-pad failures of large vehicles can cause DFO, break windows and hazard building occupants
- Focusing depends on the atmospheric conditions (pressure, wind, temperature, dew point) as a function of altitude
  - Gradient (no DFO), Inversion, Caustic, Complex
- Launch safety personnel input weather data prior to launch and run the BlastDFO application to determine if the DFO risk is acceptable



- Limited empirical data exist to validate low-pressure window breakage, shard size/velocity and human vulnerability models
- Therefore, a test program was funded to acquire low pressure window breakage (**FAA**) and human vulnerability data (**SLD45**)

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BlastDFO Model

Phase 1 Testing

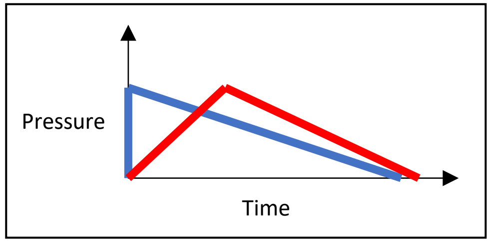
Phase 2 Testing

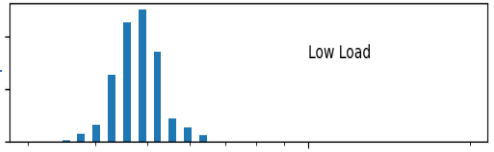
BlastDFO Model
- ray tracing
- focus zones
- pressure time history

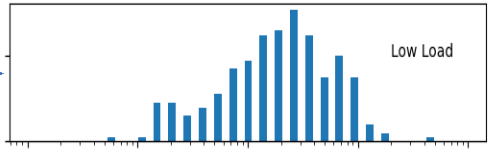
GWIN Model
- Pressure/Impulse Loading
- Shard Velocity Distribution
- Shard Mass Distribution
- Human Vulnerability Model

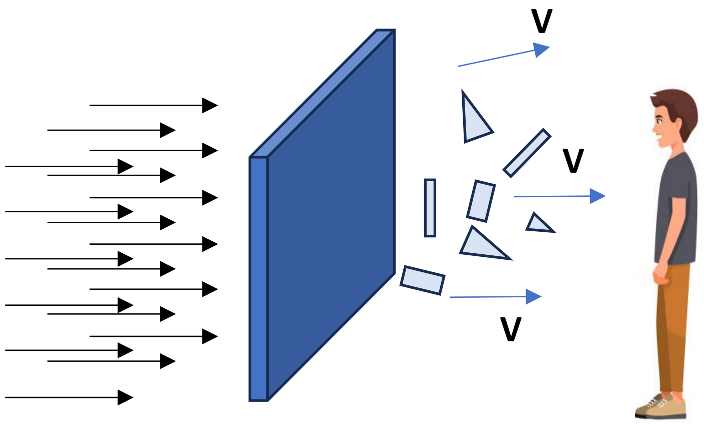
Window Breakage Testing (Shard Velocity Distribution, Shard Mass Distribution)

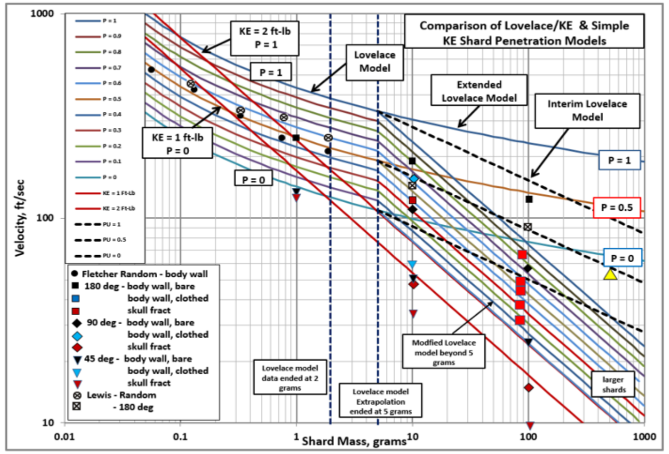
Glass Shard Drop Testing → Human Vulnerability Model









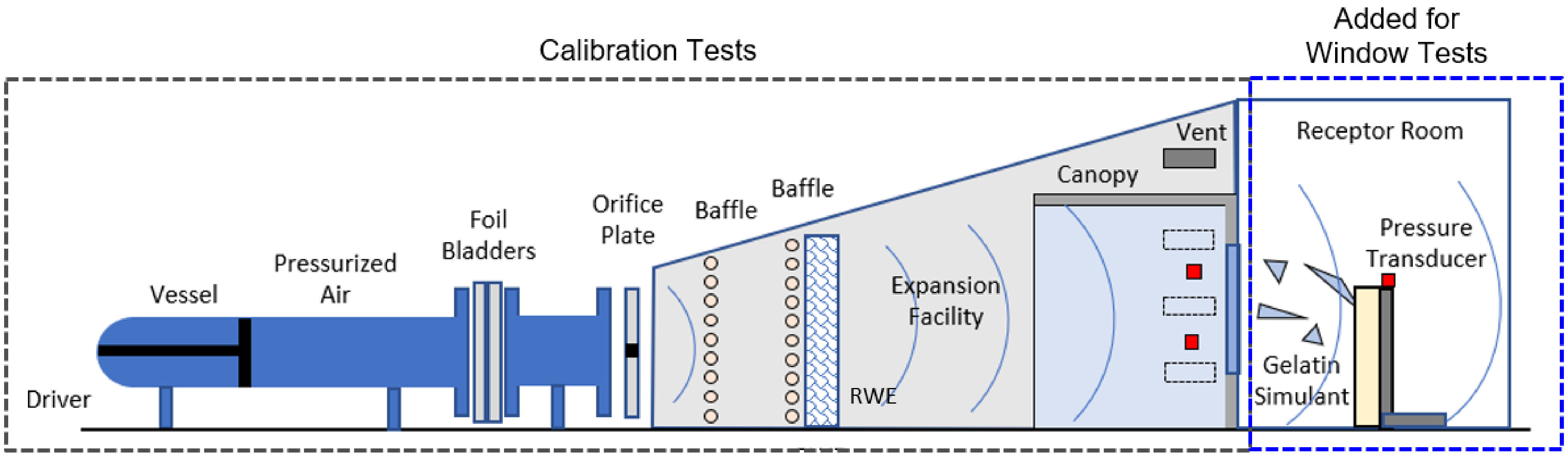


Goal: Acquire empirical data to validate the GWIN models

Phase 1 Testing
Window Breakage

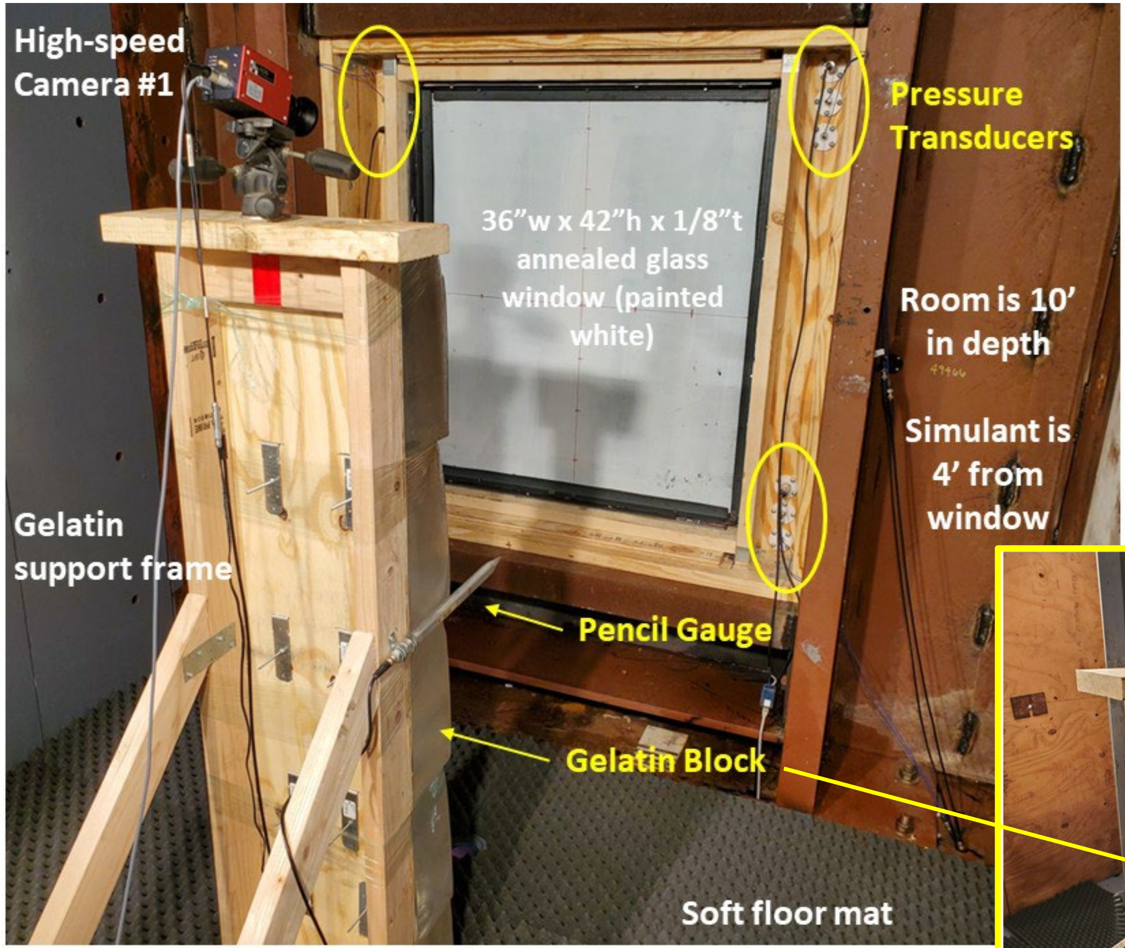
Phase 1 Shock Tube Testing

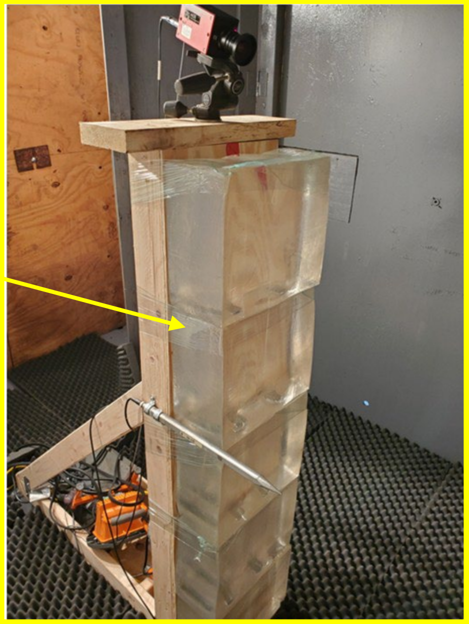
- The previous shock tube configuration needed significant modification to generate lower peak overpressures and the longer durations associated with DFO
  - Driver controls the volume of pressurized air
  - Foil bladders rupture at desired pressure
  - Orifice plates (various diameter holes) used to restrict flow and increase duration with baffles used to further restrict and delay flow
- Baffles used to further restrict and delay flow
- RWE (Rarefaction Wave Eliminator) used to reduce baffle reflections/rarefactions
- Canopy used to consolidate blast wave
- Vents in walls allow control of pressure reaching canopy and reducing wall reflections and rarefactions
- High-speed video cameras, pressure transducers and a human gelatin simulant were installed



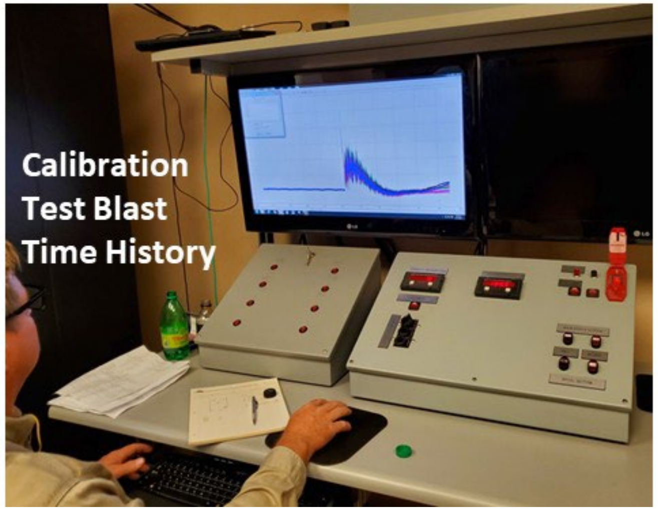
Shock Tube Apparatus

Receptor Room

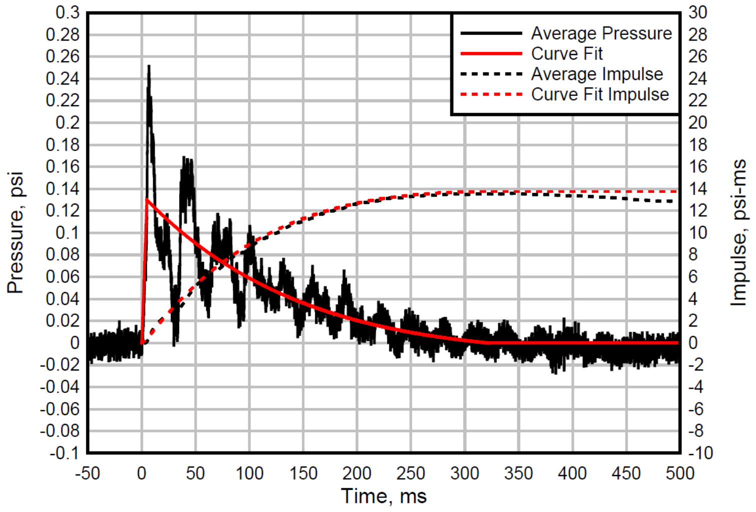




Shock Tube Control Room



Sample Test Videos



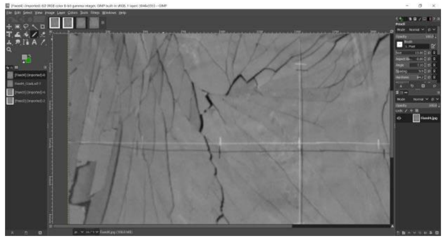
Front

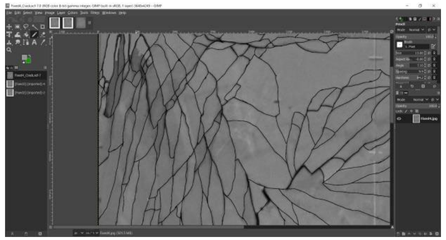
Side

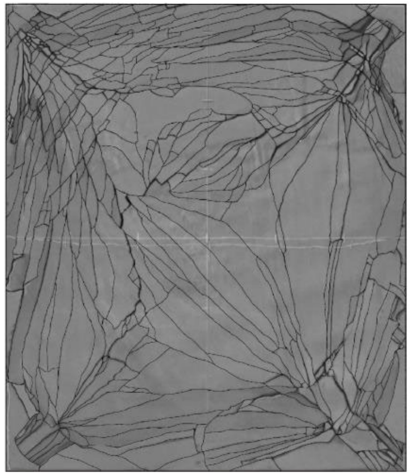
Shard Size Distribution

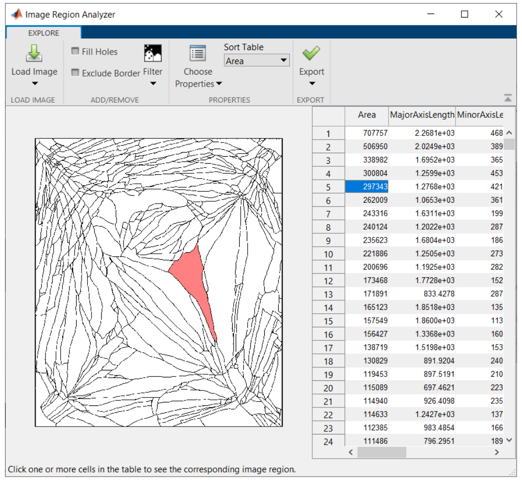
Image Processing Techniques

Used to determine shard sizes









	Area	MajorAxisLength	MinorAxisLe
1	707757	2.2681e+03	468
2	506950	2.0249e+03	389
3	338982	1.6952e+03	365
4	300804	1.2599e+03	453
5	297343	1.2768e+03	421
6	262009	1.0653e+03	361
7	243316	1.6311e+03	199
8	240124	1.2022e+03	287
9	235623	1.6804e+03	186
10	221886	1.2505e+03	273
11	200696	1.1925e+03	282
12	173468	1.7728e+03	152
13	171891	833.4278	287
14	165123	1.8518e+03	135
15	157549	1.8600e+03	113
16	156427	1.3368e+03	160
17	138719	1.5198e+03	153
18	130829	891.9204	240
19	119453	897.5191	210
20	115089	697.4621	223
21	114940	926.4098	235
22	114633	1.2427e+03	137
23	112385	983.4854	166
24	111486	796.2951	189

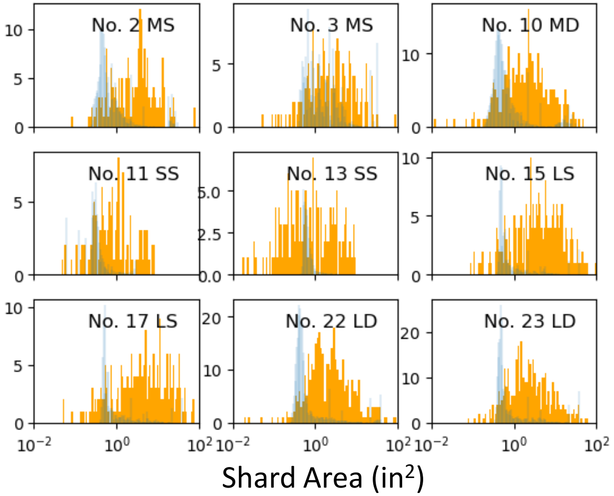
MATLAB toolboxes were used to apply masks and morphology with some manual crack line enhancement to define segments for the region analyzer

Correcting Shard Size Distributions

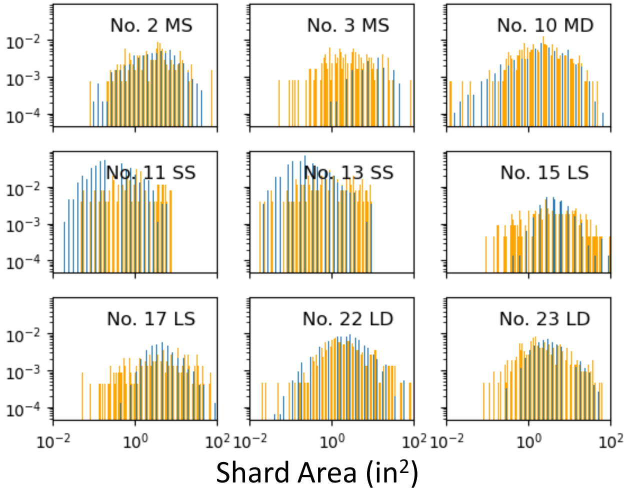
Comparisons of GWIN size vs. empirical used to update model

S-Small Window
M-Medium Window
L-Large Window
S-Single Pane
D-Dual Pane

Original Comparison



Updated Comparison



Blue-GWIN Distributions
Yellow-Empirical Data

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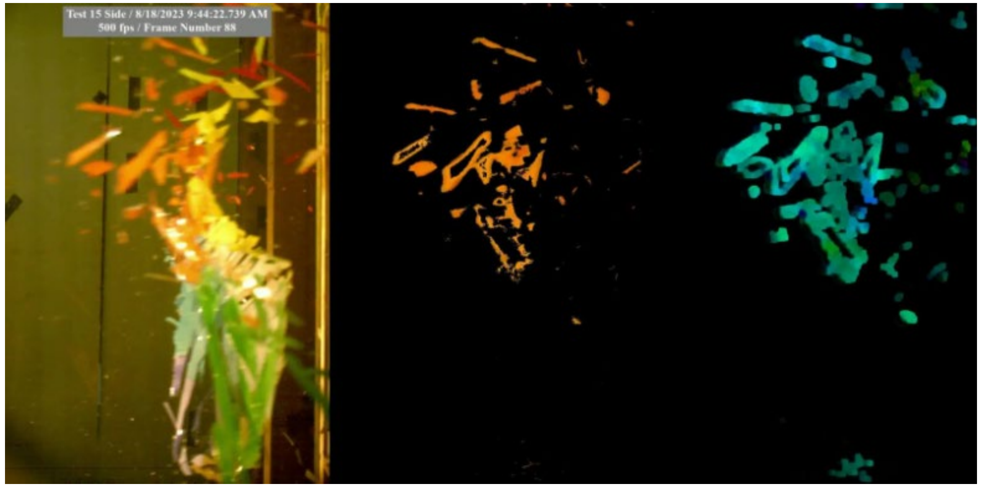
Shard Velocity Distribution

Image Processing Techniques

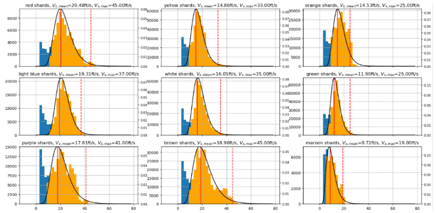
Manual and Automated Methods used to determine shard velocities

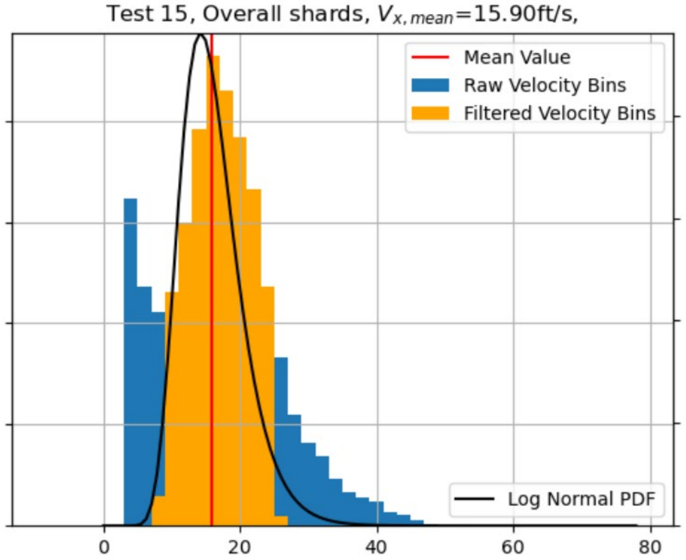


Methods include, optical tracking, color filtering, morphological transformations. Optical tracking used an optical flow algorithm based on the Farnerback method.

Shard Velocity Distribution Developed

Statistical distributions were developed based on the empirical results

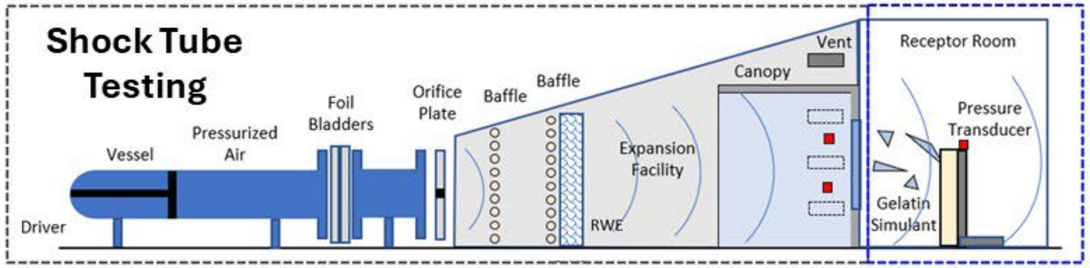




Phase 2 Testing
Human Vulnerability

Shard Drop Tests

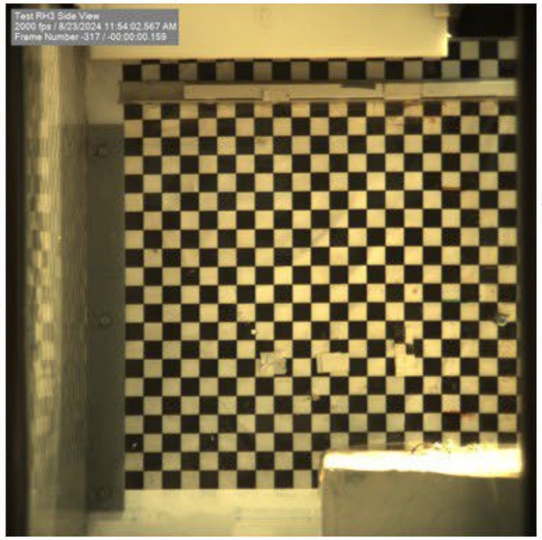
DFO Low Blast Pressure/Impulse applied to windows



Shard Velocity and Size Distributions

Shard Tumble Testing

Controlled Shard Orientation Testing

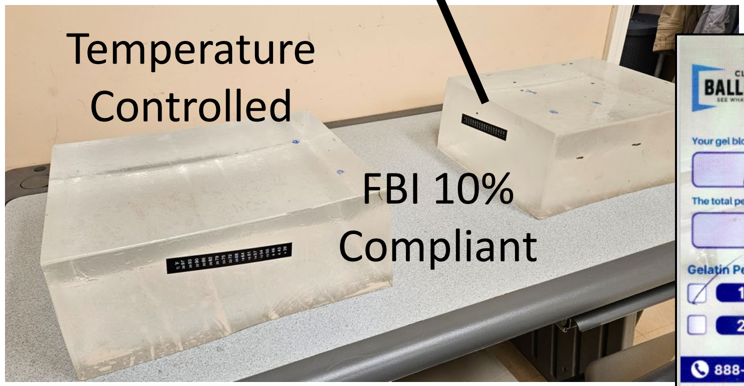


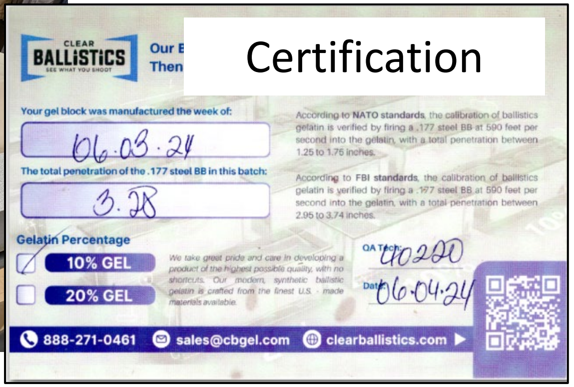
Penetration vs. shard mass & velocity

Update GWIN Models

- Shard Size
- Shard Velocity
- Rise Time Effect
- Human Vulnerability

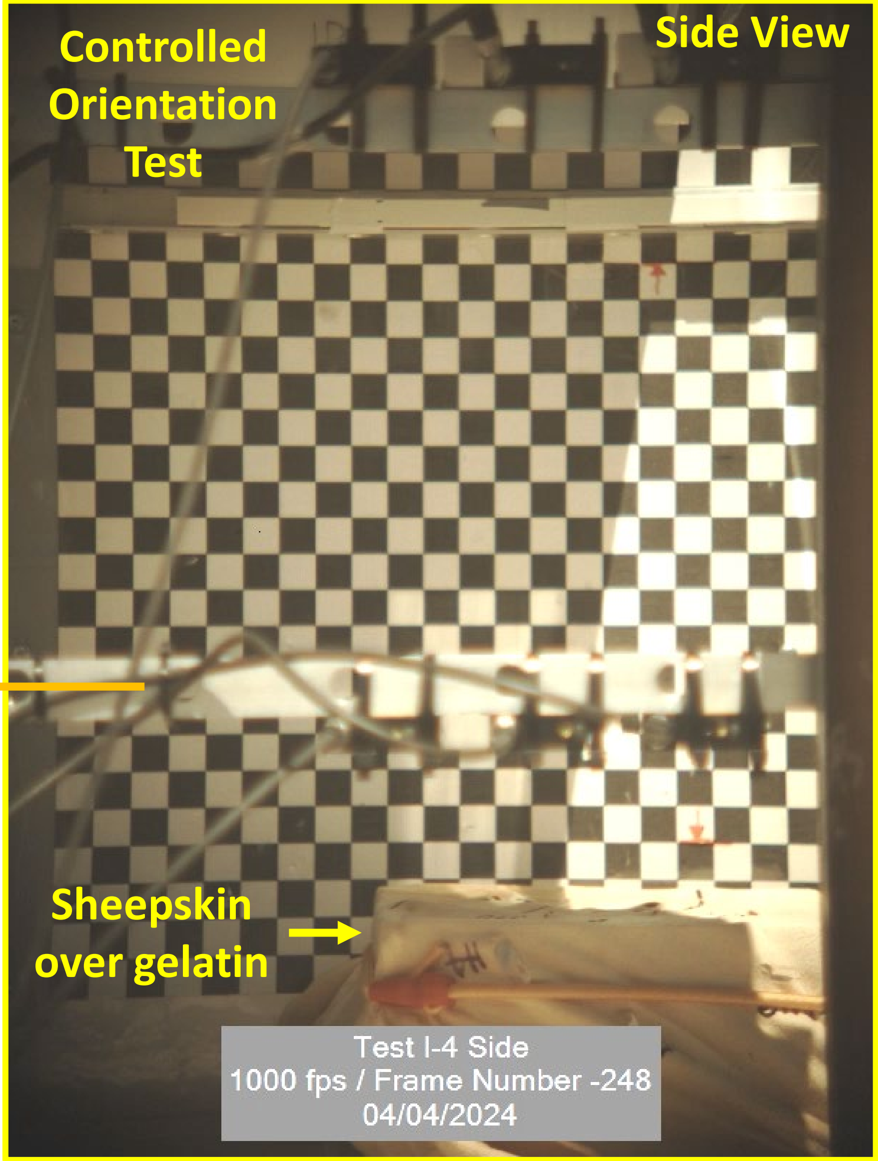
Human Gelatin and Skin Simulants

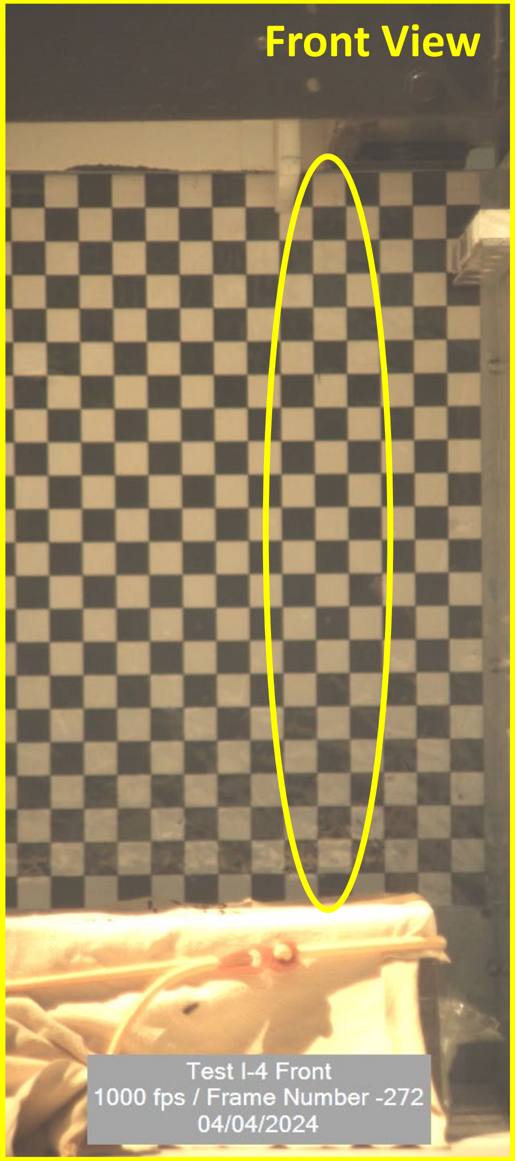




Selected based on tensile strength and BB penetration testing

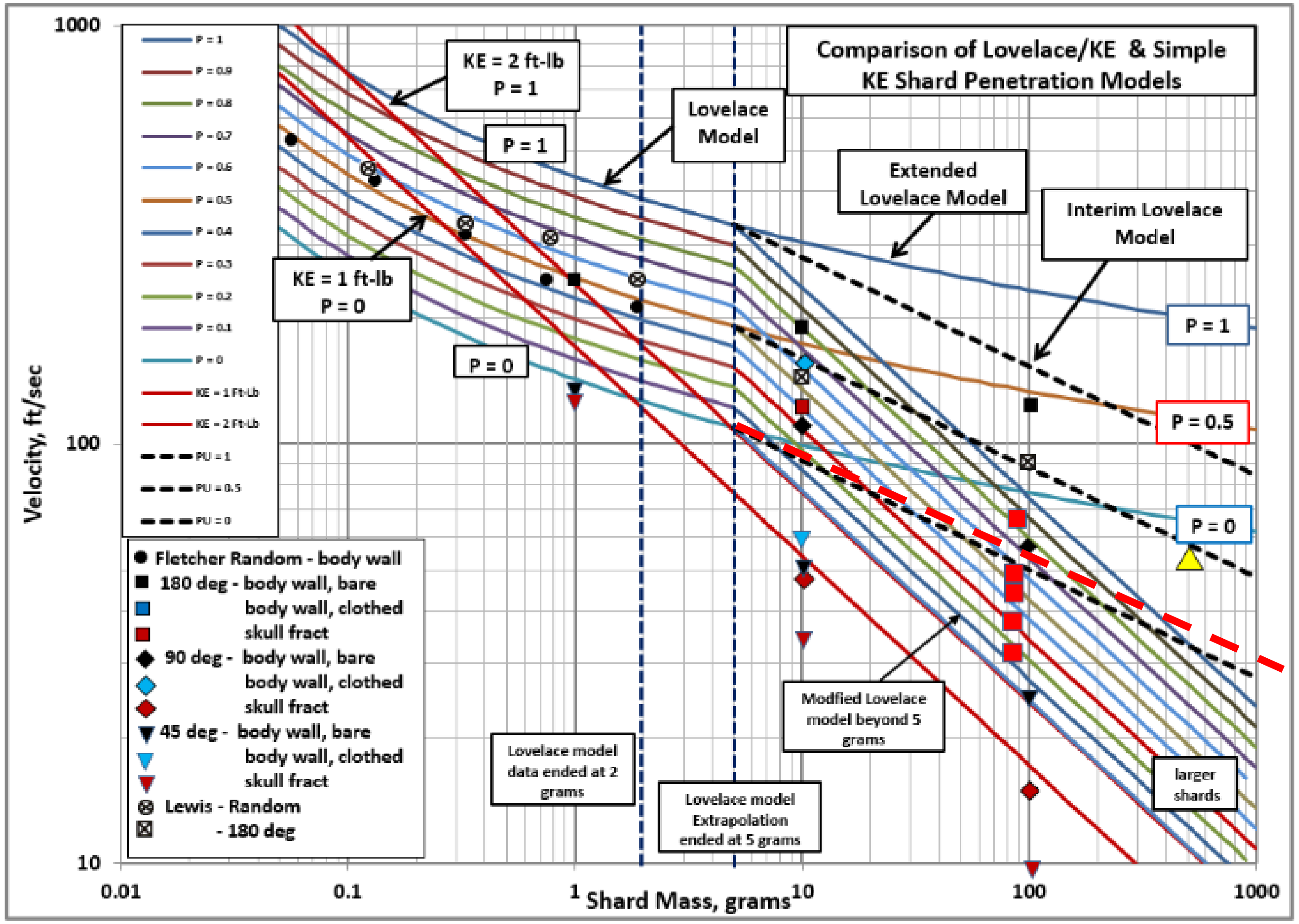
Shard Drop Tests



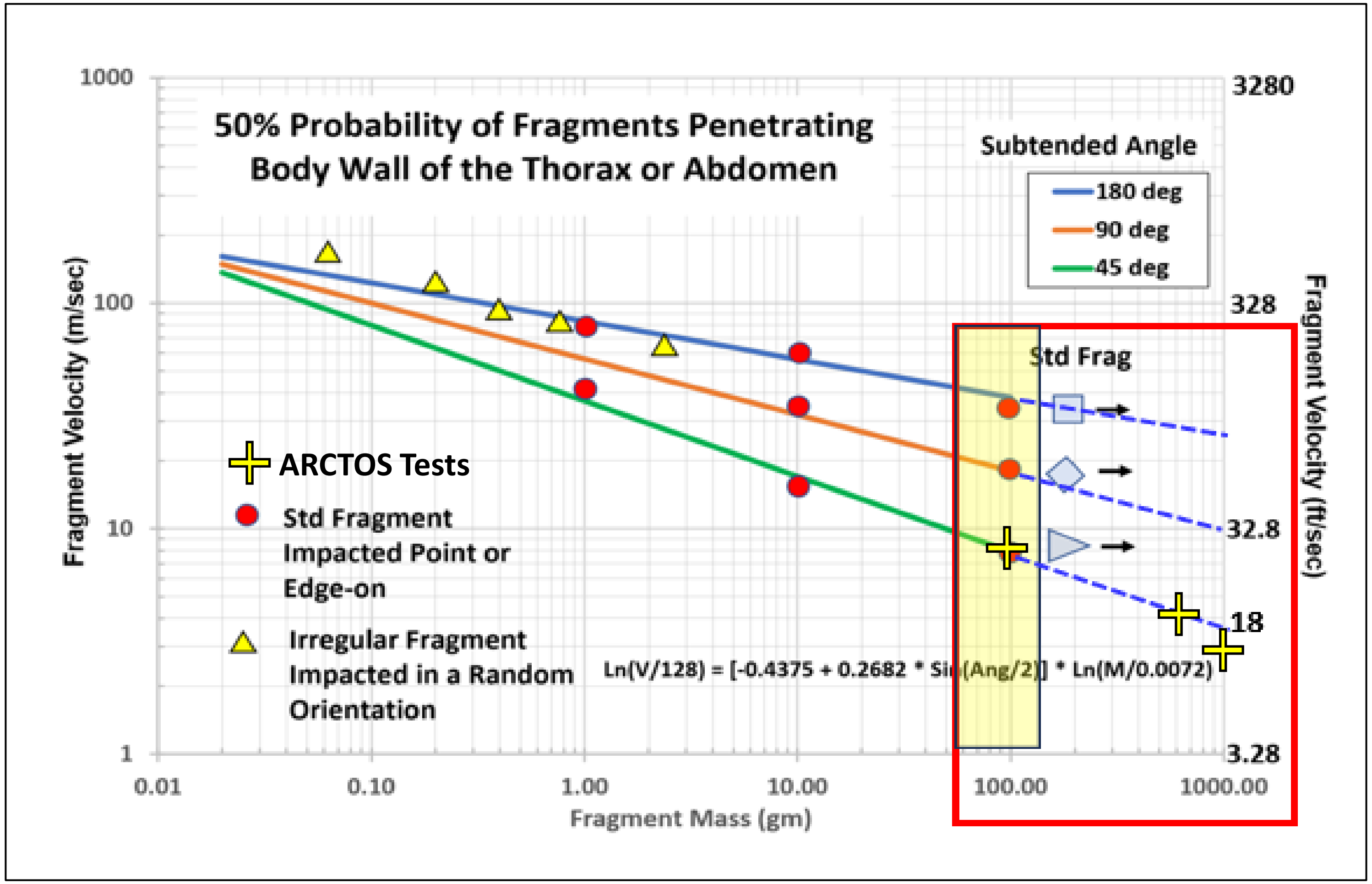


Human Vulnerability Background

- Lovelace model for masses < 5 g is well-established
  - High pressure breaks with high velocity small fragments
- Various models exist for large fragments based on limited data
  - Resulting from low-pressure breaks



Human Vulnerability Modeling



- Controlled orientation tests aligned well with Fletcher tests
  - Demonstrated validation of drop tests
- Focus was then moved to tumbling tests
  - Tumbling tests showed that 50% penetration had reasonable agreement with 90 deg Fletcher data

General Findings and Status

- Low Pressure Window Breakage Tests (Shard Characterization)
  - Shard sizes in were being misrepresented in legacy GWIN by overpredicting the number of small shards and underpredicting large shards
  - Original GWIN was over-predicting shard velocities
- Shard Drop Tests (Human Vulnerability)
  - Results showed strong agreement with existing Fletcher model for oriented shards (45 deg, 90 deg)
  - Initial findings indicate that GWIN shard human vulnerability models are somewhat under-conservative above 20 g;
- Status: Finalizing human vulnerability model and code implementation