Non-Explosive Blast Pulse Loading of Armor Panels and Materials

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Objectives

• Generate dynamic pressure pulse to mimic close-in blast detonation on armor panels
  – non-explosive testing with UCSD Blast Simulator
  – wide area (24 x 24 in.) sandwich armored panels
  – spatially and temporally varying

• Establish dynamic test methods with fast actuators and gas gun to produce high strain rates and deformation levels

• Define modeling capability with FEA to enable virtual armor design studies
Dynamic Load Pulse Generation

- Fast-rate loading to excite dynamic response
  - Similar to explosive blast loading
- Use impact to impart desired impulse/momentum
- Match total impulse and tune loading history via:
  - Projectile mass and geometry
  - Velocity
  - Pulse shaping media

\[
\text{Impulse of explosion: large initial pressure } \quad P_A, \text{ short duration pulse } T_A
\]

\[
\text{Specific Impulse } = \frac{P_A T_A}{2} = \frac{P_B T_B}{2}
\]

Simulated blast: finite loading time \( T_{B1} \), lower pressure \( P_B \), longer duration pulse \( T_{B2} \)

Scalable
Investigation of Vehicle Armor Panels for Blast Protection
- Armorworks / US Navy
- ONR Grant No. N00014-11-C-0288

- Develop test methodology for *quantitative measurement of blast impulse absorption*
  - evaluate/rank armor panel designs
- Tile array applies impulse to flexible target
  - represent buried blast charge

Test Video
Large Panel Projectile Design

- Tiled projectile selected for wide area pressure pulse
- Bi-metal blocks with spacers for spatial and temporal control
- Shaped foam tips for tailored pressure pulse
Blast Test Details

• **Non-explosive:** tiled array launched at 24.6 m/s for 50.3 kg projectile package total mass
  – 7,250 Pa-s specific impulse corresponds to 1.74 kg TNT at 305 mm standoff

• **Actual blast:** tests conducted by Oregon Ballistic Lab at remote desert field site

• Target panels 610 x 610 mm

• Transmission plate 13.7 kg
### Large Panel Results

#### Non-Explosive Trans. Plate Acceleration

![Graph of non-explosive transmission plate acceleration over time](image1)

#### Blast Trans. Plate Acceleration

![Graph of blast transmission plate acceleration over time](image2)

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<table>
<thead>
<tr>
<th>SPECIMEN</th>
<th>ACCELERATION &amp; REDUCTION TO RHA</th>
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<tbody>
<tr>
<td></td>
<td>Areal Density (kg/m²)</td>
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<tr>
<td>ID</td>
<td>(g)</td>
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<tr>
<td>RHA</td>
<td>48.8</td>
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<tr>
<td>1436</td>
<td>33.8</td>
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<tr>
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<td>1574</td>
<td>24.7</td>
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<tr>
<td>ALUM</td>
<td>25.7</td>
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- Transmitted pressure accelerates transmission plate
- Acceleration directly measured by shock accelerometer at transmission plate CG
- Average calculated during time while transmission plate accelerates to max velocity
- Best performance relative to RHA steel:
  - 1436 & 1571: 35 to 37% reduction of average initial acceleration
  - 1437 & 1571: 72 to 76% reduction of max acceleration
Coupon Specimen Level Testing

- Projectile: 3.18 mm alum. disc on foam body launched at 35 to 95 m/s
- Compare transmitted pressure pulse of sandwich designs vs RHA steel
- Collect data supporting simulation development

**Damaged Specimens**

35 m/s

95 m/s

Up to 75% Reduction Relative to RHA
FE Modeling Methodology

- Accurate FE models developed to enable virtual armor design
- Models established/validated from tests at different size class:
  - physically-accurate models established via simulation of material coupon and small component (gas gun) tests
  - apply to large panel simulation
**Large Panel Results**

**Non-Explosive Simulation**

**Pressure Pulse (Ideal) Simulation**

Deformation Profiles

Transmission plate velocity measured with accelerometer and high speed camera in comparison to FEA predictions.
Conclusions

• Non-explosive large panel tests can approximate damage modes and deformation profile for flexible armored panels
• Projectile system is scalable and highly repeatable (w/in 1%)
  – consistency allows quantitative comparison of various armor panel designs – e.g., 76% reduction in max transmitted acceleration w.r.t. RHA
• Hopkinson bar coupon tests give insight into pressure pulse attenuation independent of boundary conditions effects
  – supports FE model development
  – direct method to assess various core materials and configurations (layering, honeycomb cell size, etc.)
• Hierarchical FEA model construction
  – material and small specimen tests used to establish physically-accurate models
  – scale-up to larger specimen/structures (e.g., configured panels)
  – generic methodology applicable for enabling virtual armor design
Description of Impact Research Facility

• Gas guns – for projectile impact and penetration research
  – 79 mm bore gun – max vel. 250 m/s
  – 25.4 mm bore gun w/6.7 m (22 ft.) barrel
    – expected max vel. 1000+ m/s
  – source of high-speed dynamic loading
    • launch flyer plate and other projectiles
    • impact onto specimens mounted to Hopkinson bar

• Hopkinson bars
  – 76.2 mm dia. x 3.2 m length (126 in.)
  – SHPB: 25.4 mm dia. x 1.27 m length (50.5 in.)
  – use for studying projectile properties and developing models
76.2 Mm Hopkinson Bar: High-Rate Dynamic Loading to Large Deformation Levels

- Axial loading of specimen through transfer shaft, similar to SHPB
- Dynamic strain rates tested at 3,700 s\(^{-1}\) controlled by projectile velocity
- Well-controlled coaxial loading produces high specimen crush levels (over 50%) – controlled by projectile KE