



Blast effect reduction using mitigating media

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Blast impulse? Blast effect mitigation?

Blast impulse is:

- momentum transfer per unit area from blast waves into targets (bar-ms, Pa-s, psi-sec, etc.)
- the area under the pressure-time curve of a blast wave
- the mechanism that knocks down barriers, destroys vehicles, and hurls people against walls

Blast effect mitigation means

- reducing impulse and peak pressure
- reducing/suppressing heat release from detonations and deflagrations, which can prevent post-blast fires (“Keep cool and carry on...”)



Reducing peak pressure is often easy; reducing blast impulse is difficult

Sir Isaac Newton was right: energy (total) and momentum (total) are conserved (reversible processes) when 2 masses collide....

- pressure is reduced, velocity increases as fluids pass through nozzles and screens
- pressure recovers, velocity drops as the fluid passes into the surroundings (ambient conditions)
- ...BUT friction, viscous drag, and heat transfer (*irreversible* energy and momentum processes) extract energy *and* momentum from the fluid

Blast impulse reduction is possible through the artful use of every possible combination of irreversible processes and mechanisms

Why mitigate blast effects? Q/D

- In the US, regulations exist for separation distances (“ D ”) from explosive hazards (“ Q ” for quantity); Q often called net TNT-equivalent charge weight (“ NEW ”) or “ NEQ ”
- D is based upon “allowable pressures” suitable for the relevant situation (separation from public highways and communities, separation between explosives manufacturing facilities, separation between facilities on military bases, etc.)
- Q/D constraints limit the locations where magazines, aircraft “bombing up” operations, even military units disembarking in ports (in peacetime) can be when near urban areas
- Impulse is the proper criterion, but a linkage between peak pressure and impulse is assumed in these regulations (crude, but pressure is easier to measure)
- **BOTTOM LINE:** blast *mitigation reduces the net effective $Q/NEQ/NEW$* , which under Q/D regulations would greatly expand usable military base areas, allow safe operation of energetic material-handling operations near highways, ports and resources
- **BONUS:** blast-mitigating containers may allow Hazard Class **1.1** (“detonating”) materials to be reclassified as **1.4** (“insensitive”), thus substantially reducing limits to public roadway and railway transportation use



Why mitigate blast effects? Confined spaces

- Confining blasts inside structures (buildings, ships, magazines) is limited to small charge weights ($Q/NEQ/NEW$) because pressure and impulse will cause structural failure
- Venting helps, which allows confinement of somewhat larger NEQ , but blast pressure and impulse builds up faster than vents can relieve (due to distance from vents, time delay before opening, choked flow in ducts that limit vent effectiveness)
- Venting is not possible inside ships and submarines, inside large buildings, inside mines)

Blast mitigation inside ships & submarines, structures, & mines is possible without venting through exploitation of irreversible processes (although venting does help when one can use it...)

Mechanisms for rapidly dissipating blast energy and momentum in granular media

- Multitudinous collisions between granules disperse momentum
- Phase change materials (“PCMs”) absorb energy (kJ) through the enthalpy of fusion or decomposition (ΔH_m , kJ/kg)
- Aerodynamic drag [proportional to (velocity)²] due to huge specific surface area
- Heat transfer from hot gas to granular media due to huge specific surface area
- Interference heating (in gas flow velocity > Mach 8)*

*Interference heating = breakdown of the boundary layer due to turbulent flow/shock wave interactions; heat transfer across boundary layer increases ~ 10x



UK MoD DERA (dstl) 1996 tests (200g C-4 spherical charges detonating in 51cm x 51cm x 51 cm boxes)

Shot	Filler/Panel	Incident Pressure	Impulse	Pressure Reduction	Impulse Reduction
		Average (kPa)	Average (Pa-s)	(P/CONWEP P)	(I/CONWEP I)
DERA*		326.4	73.0		
2	Perlite-filled box	< 35.2**	No result	No result	No result
3	Perlite-filled panels***	39.7	30.0	87.8%	58.1%
4	Foam bead-filled box	81.5	33.1	75.0%	54.7%
5	Foam bead-filled panels	133.8	46.4	59.0%	36.4%

*DERA predictive software. CONWEP predicted impulse at 200g C-4 to be 71.0 Pa-s.

**Trigger for data acquisition system set at 35.2 kPa, so no pressures recorded.

***Panels on 4 vertical sides. Perlite-filled panels 1,7cm thick, foam bead-filled panels 1.5cm thick



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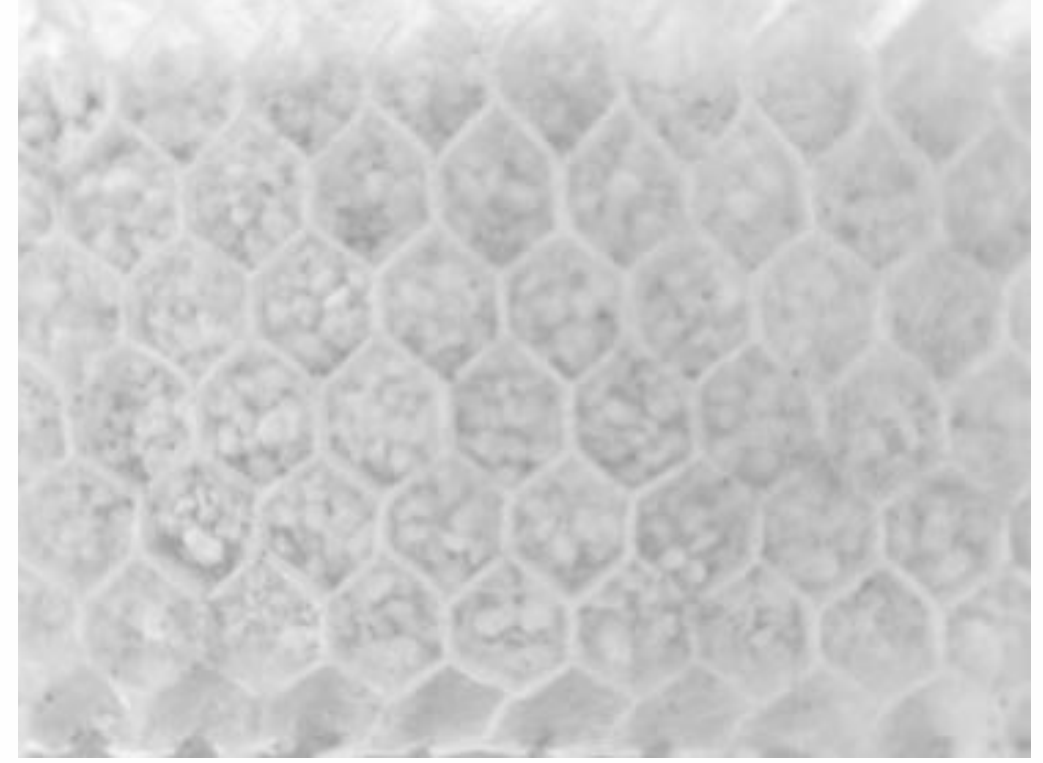


DERA (now dstl) 1996 test panels

Foam bead filled, 3,8 cm thick
honeycomb core



Perlite (volcanic foam glass)-filled
3,7cm thick honeycomb core



Recent research (2024-2026)

- Adapting DERA/dstl test setup & protocol, Southwest Research Institute (“SwRI”) conducted 3 test series using mitigating media in (a) panels & (b) granular media-filled cylinders surrounding charges
- Bare cylindrical C-4 cylinders used in all tests, ranging from 200g to 600g mounted in the geometric centre of each box
- Single-wall corrugated kraft boxes all 51cm x 51cm x 51cm mounted atop 150 cm cardboard tube (to record pressure data without reflected shock influence)
- Pressure transducers placed at 1m & 2m from charge surfaces
- High-speed video with still photo captures



Panels along walls

Panels emplaced (no panels on bottom of box)



Charge mounted on foamboard



Concentric kraft cylinders with granular 2-phase media fillers

Vermiculite-filled inner annulus,
aerogel fill outer annulus sealed with
thin plaster



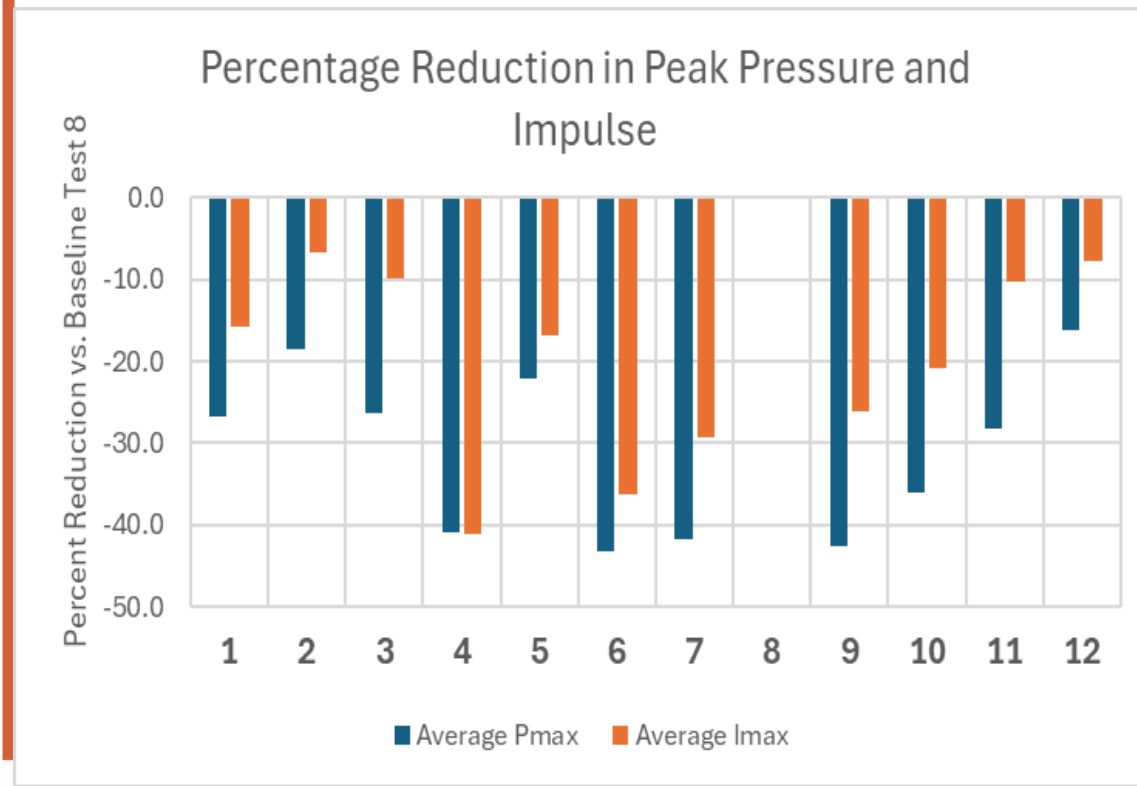
Baseline (no media filling) with charge



2026 test results (600g C-4 cylindrical charges)

SwRI-computed mitigation for different configurations (Shot #8 was baseline)

Detailed data for adjacent table



Configuration*	Tubes/Panels	Filler Mass (g)	Impulse**(1m)	Impulse**
V (front)/MT (back)	Tubes	723	111.7	69.0
V (front)/MT (back)	Panels	1,393	140.7	60.0
V (front)/lactate (back)	Tubes	2,029	53.1	57.2
V (front)/PCM (back)	Tubes	1,781	72.4	57.2
V (front)/aerogel (back)	Tubes	856	111.7	73.1
Vermiculite (17.5cm)	Tubes	1,571	75.2	63.5
Foam beads (17.5cm)	Tubes	547	131.7	70.3
CONWEP (600g C-4)	Free air	0	149.0	77.9
Perlite 4.3cm (200g C-4)	Panels	3,250	33.6	N/A
Foam beads 3.8cm	Panels	217	8.0	N/A
Foam beads 22.5cm	Filled box	,360	15.4	N/A
DERA predicted****	Free air	0	73.0	N/A

*"V" is vermiculite filler, "MT" is empty **Impulse in Pa-s. ***DERA prediction for 200g C-4. No readings/predictions for 2m.

NOTE: Aerogel product is a saturated felt, not a granular/flowable medium

Blast mitigation without PCMs (600g C-4 charges)

5 ms after detonation (unmitigated on left of split-screen)



• 75 ms after detonation. Vermiculite in inner annulus, unfilled outer annulus (note glowing gas in upper right)



Blast mitigation with PCMs (600g C-4 charges)

Inner annulus vermiculite-filled, outer annulus PCM-filled. 5 ms after detonation



75 ms after detonation. Small amount of flame at base because no media is present on bottom of box (same for all tests)



Future research & development

- Modeling blast mitigation requires a much greater experimental database
- Parametric relationships of particle and shock wave velocities, impulse, and temperature reductions as functions of blast intensity, media density & thickness, media total mass, specific surface, and granular media characteristic dimensions (and dimension range) cannot be established without more experimental data.
- The optimum thickness or placement of PCMs requires much more experimentation since packed beds of any kind (sand, powdered PCMs, granular 2-phase media) increase impulse and reflected shock parameters
- Experiments by Halsey & Berry* showed substantial reductions of fragment KE when cased munitions (bombs & projectiles) packed in granular pumice (another volcanic foamed glass) detonate; experiments must be performed to quantify KE reductions and obtain quantified parametric data to model + design protection means

*Halsey, C. C. & Berry, S. L.; *Expanding Pumice Technology to the Protection of Missile Warheads from Sympathetic Detonation*; paper presented at DOD Explosives Safety Board Explosives Safety Seminar, Las Vegas NV, 20-22 August 1996



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