Experimental and Computational Study of Water Blast Mitigation Associated with Different Water Configurations

Andrew J. Zakrajsek, Eric J. Miklaszewski, and Steven F. Son
Purdue University, azakrajs@purdue.edu, sson@purdue.edu

Abstract

An explosion yielding a shock wave is just one of the many threats the US faces. This threat can cause damage to equipment, structures, and cause significant risk to personnel. These threats define an immediate importance for understanding blast mitigation techniques via readily available mitigants. Specific blast mitigation fundamentals using water are being studied. Various water configurations are being investigated to quantify the different blast mitigating potentials for each configuration. These studies can be used to help advance blast mitigation for various areas.

Relevance

- It is extremely important to study different configurations of water when trying to understand the fundamental mitigation mechanisms.
- Up to now there is scarce literature that addresses multiple water configurations.
- Four fundamentally different water configurations are being considered here.
- The fundamental mitigation mechanisms such as momentum transfer, impedance differences, and evaporation are being explored.

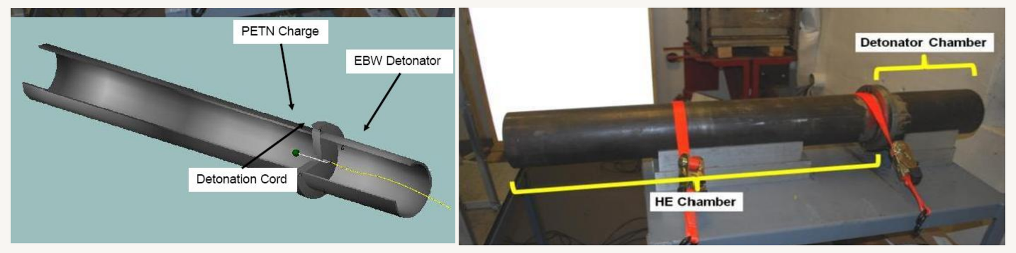
Related Research Findings

- Completed water spray mitigation tests compare well with previous spray mitigation data obtained by the Naval Research Laboratory [2].
    - Even at different testing conditions both groups of results showed around 40% overpressure mitigation.
- Initial results using water sheets have shown an overpressure reduction of up to 81%.
- Water sheet results match numerical models [1].
- Additionally we show that the closer the water sheet is to the explosion the higher blast mitigation percentage.

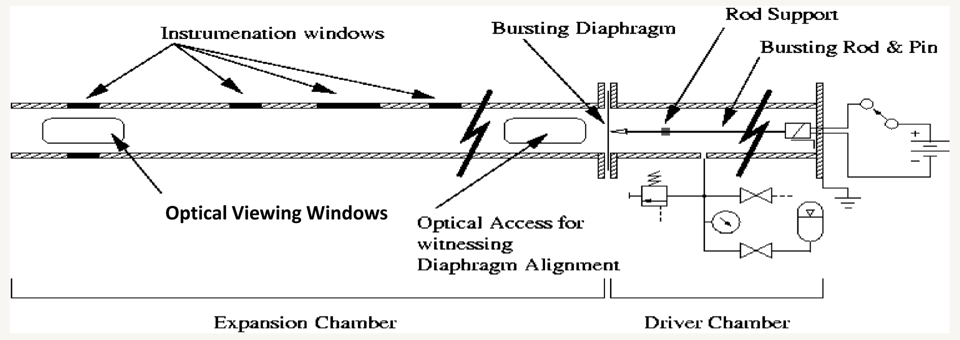
Technical Approach

Laboratory testing using an explosively driven shock tube and a pressurized air shock tube are used for configurations including: solid water barriers, water sprays, water sheets, and individual droplets of water.

- The water sheet facility is the only known location of large scale experimental water sheet testing.
- Experiments are documented with pressure measurements and high speed imaging of the shock wave water interaction using shadowgraphy techniques.

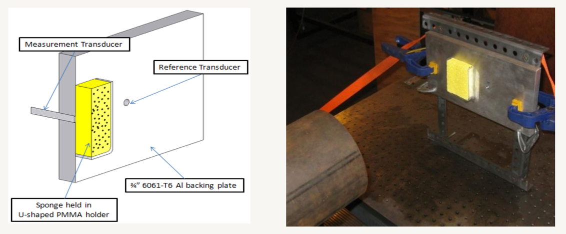


Explosively Driven Shock Tube



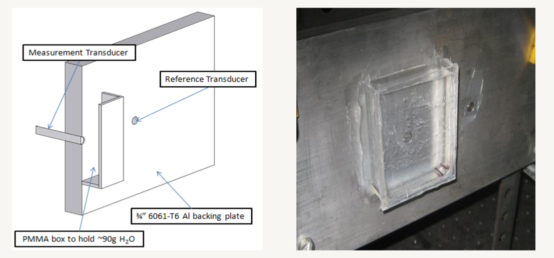
Shock Tube

Solid Water Barriers



Test	Peak Pressure (psig)	Impulse (psig-ms)	Positive Pulse Duration (ms)
Plate Reference	73.67	10.41	.42
Dry Sponge	70.34	19.01	.67
Wet Sponge	34.07	25.03	1.81

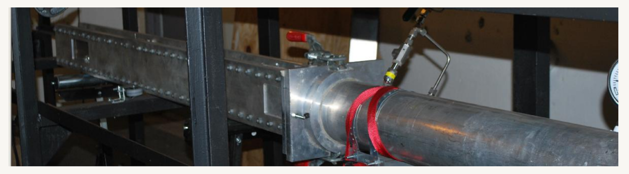
Sponge Test Set-up and Results



Test	Peak Pressure (psig)	Impulse (psig-ms)	Positive Pulse Duration (ms)
Plate Reference	65.54	10.72	0.51
Dry Box	28.78	7.95	0.65
Wet Box	51.26	6.20	0.23

Water Barrier Set-up and Results

Individual Water Droplets



Individual Droplet Test Rig

Droplet Breakup Images

Water Spray Tests

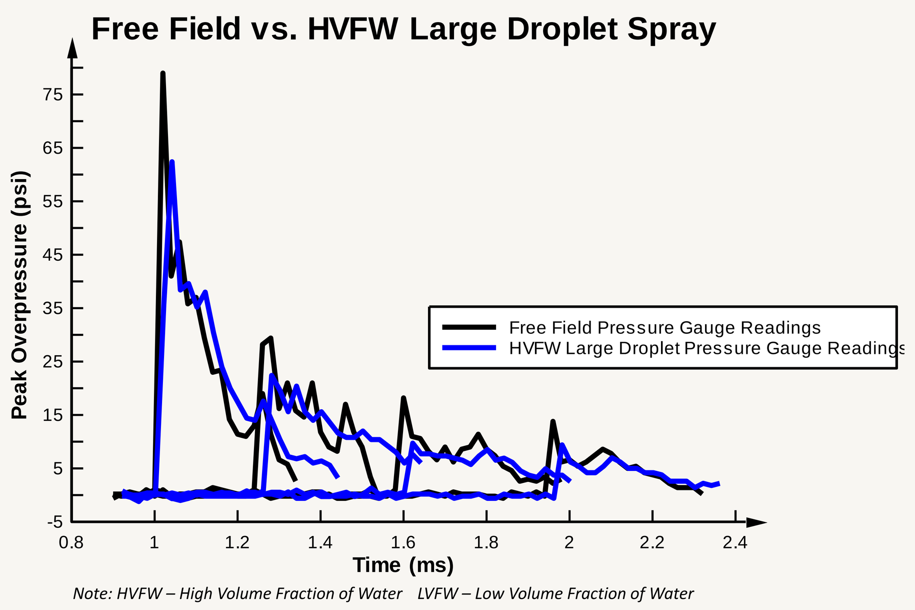
Water Spray Test Set-Up

Test	Average Peak Pressure at 8 in (psig)	Average Peak Pressure at 14 in (psig)	Average Peak Pressure at 20 in (psig)	Average Peak Pressure at 26 in (psig)
Free Field	78.90	29.90	18.20	13.80
LVFW Small Droplet	46.75	19.00	8.10	6.75
LVFW Large Droplet	53.60	19.60	8.30	6.50
HVFW Small Droplet	42.20	15.30	15.00	10.90
HVFW Large Droplet	56.90	22.60	10.31	8.33

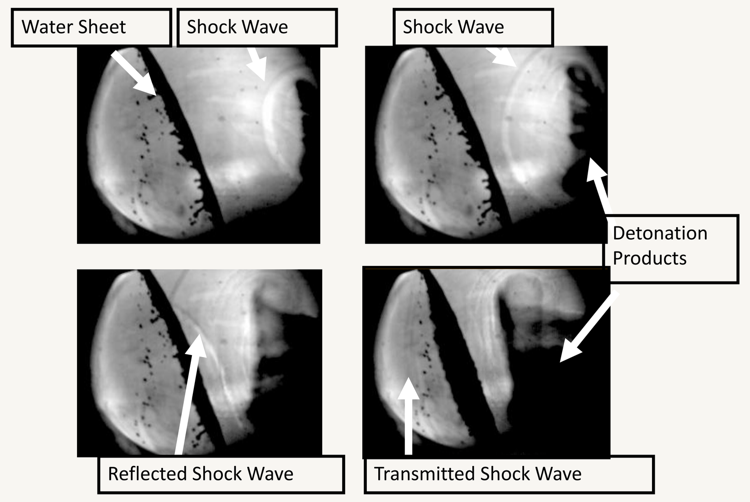
Test	Averaged Positive Pulse Duration at 8 in (ms)	Averaged Positive Pulse Duration at 14 in (ms)	Averaged Positive Pulse Duration at 20 in (ms)	Averaged Positive Pulse Duration at 26 in (ms)
Free Field	0.34	0.30	0.40	0.38
LVFW Small Droplet	0.36	0.42	0.45	0.32
LVFW Large Droplet	0.42	0.38	0.35	0.36
HVFW Small Droplet	0.32	0.38	0.48	0.38
HVFW Large Droplet	0.43	0.38	0.41	0.37

Test	Averaged Impulse at 8 in (psig-ms)	Averaged Impulse at 14 in (psig-ms)	Averaged Impulse at 20 in (psig-ms)	Averaged Impulse at 26 in (psig-ms)
Free Field	8.20	4.40	3.20	1.90
LVFW Small Droplet	6.65	3.75	2.00	1.55
LVFW Large Droplet	7.30	3.40	2.10	1.40
HVFW Small Droplet	6.60	3.30	2.40	1.90
HVFW Large Droplet	8.50	4.10	2.35	1.40

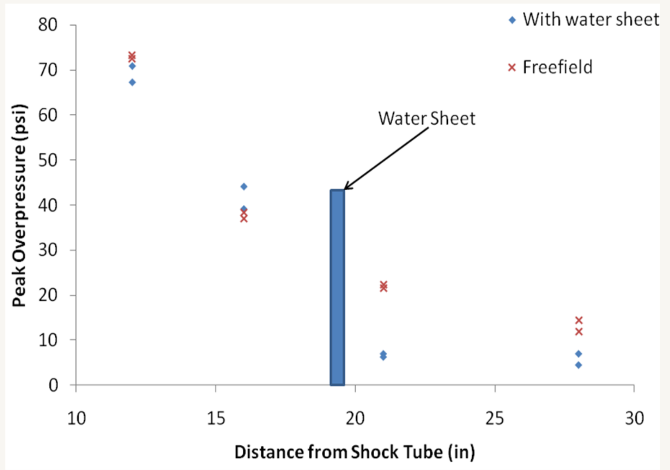
Water Spray Tabulated Results

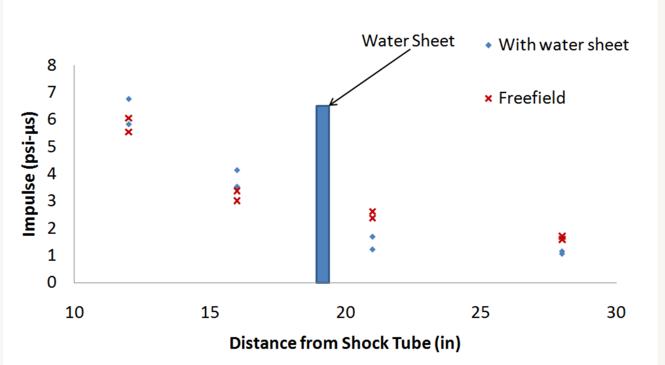


Water Sheet Tests



Shadowgraph of Water Sheet-Shock Interaction





Free Field Vs. Water Sheet, Peak Overpressure and Impulse

Accomplishments Through Current Year

- Obtained data with four fundamentally different test configurations.
- Modeled the shock wave –water interactions using COMSOL.
- Matched results from previous publications, including experimentally demonstrating that blast mitigation increases with increasing shock strength.
- Have begun elucidating fundamental mechanisms for blast mitigation which will benefit development of blast mitigation technologies/products.

Importance of Future Work

- With continued work a detailed analysis of the different water configurations can be completed, highlighting the most effective water blast mitigation configurations.
- A 3D COMSOL model is being developed generate detailed blast wave-water interactions.
- Highlight importance of water configuration's geometry, rather than mass loading, when comparing blast mitigation of sprays and sheets.

Opportunities for Research Transition

Knowing the water mitigation mechanism that provides the largest mitigation of the blast overpressure is very beneficial:

- For designing protective systems for mitigating blast waves.
- For designing storage facilities for ammunition, energetic materials, and other possibly destructive materials.

A full understanding of the different blast mechanisms associated with water may be beneficial for other mitigant materials:

- Soldiers helmets, padding, and shields.
- Structures and buildings.
- Equipment, vehicles, and vessels.

Publications Acknowledging DHS Support

- Abstract Submitted on 2/10/11 to: The 17th APS SCCM Conference; 26th June - 1st July, 2011 Chicago .

- Journal paper submission to Springer Shock Waves Journal is planned for April 2011.

Other References

[1] Numerical Simulation of Water Mitigation Effects on Shock Wave with SPH Method - Published in– Transactions of Tianjin University Journal (Springer), 2008.

[2] Blast Mitigation Using Water Mist: Test Series II – Naval Research Laboratory, NRL/MR/6180—09-9182, published in 2009 by NRL.

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied of the U.S. Department of Homeland Security.