Water-Mist Mitigation of Quasi-Static Pressure Buildup in Enclosures Subjected to an Explosion

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Introduction

There has been considerable interest in the last few years in developing methods for protecting general spaces from explosive blasts such as from weapon or terrorist attack. Although there is a considerable amount of excellent research into protecting specific spaces (such as weapons storage spaces, etc.), many of these technologies are difficult and expensive to apply to a wide range of spaces of interest. One method that has been extensively researched for off-shore platforms is the use of water mist or sprays for mitigation. With water mist systems being implemented in the machinery spaces of LPD-17 and DD(x), there is considerable interest in the possibility of using them in a dual-role function both for blast mitigation and fire suppression. Because of this, an assessment of their capability with respect to blast mitigation is of great value. The present research attempts to obtain a more accurate understanding of the interaction between water mists and the flow-field generated by a blast wave, and to assess the mitigation capability with water mist systems. Because of our current interest in terrorist and missile attacks, we examine pressure reduction related to an explosive blast of TNT, although other common explosives can also be investigated with our current model.

Fundamental Issues

There are three main ways that water mist can reduce the pressures and impulses generated by explosions. First, the water-mist absorbs momentum from the explosive gases, lowering the overall velocity and thus the kinetic energy associated with the gases. Second, the water-mist absorbs a considerable amount of the explosive energy from the gas through vaporization. Third, for oxygen-deficient explosives, if the water-mist can penetrate into the reactive zone, it can potentially quench the reactions and reduce the effect of the secondary fireball. Although this does not effect the blast-front pressure (and thus the maximum overpressure felt at any given point), it can significantly reduce the pressure development for explosives detonated within enclosures. The current research is focused on examining the effect of water-mist on explosions in enclosed spaces, both in terms of the initial blast-front pressure and the development of quasi-static overpressure. For mitigating blast front pressure, momentum extraction appears to be the main mechanism based on earlier work (Schwer and Kailasanath, 2003). For quasi-static pressure all three methods may become important. By doing multi-dimensional time-accurate simulations, we hope to elucidate both the effectiveness and the main mechanisms through which water-mist works to reduce the quasi-static overpressure.

Recent Progress

For the simulations performed in this paper, we are interested in the dynamics of the flow after detonation of the explosive. For that reason, we use a fairly simple model for the initial explosive, but have a detailed model for the resulting expansion of the explosive product gases. We use a time-accurate, multi-phase, multi-dimensional modeling approach to investigate the effect of different water mist configurations on pressures developed within the computational domain. For modeling the spray, we chose the Eulerian-Eulerian sectional approach introduced by Tambour (1984) and expanded on by Laurent and Massot (2001). The dispersed-phase conservation equations are developed by grouping droplets of similar sizes together into sections. The solution procedure involves solving M+1 sets of conservation equations, where M is the number of sections being simulated. Each set of conservation equations is solved independently using an explicit FCT algorithm of Boris and Book (1973), with the cross-coupling source terms added explicitly at the end of the dispersed-phase step. For oxygen-deficient explosives where all the fuel is not oxidized in the detonation, a secondary fireball will occur as the explosive gases are expanding and mixing with the air. This reaction front is behind the blast-front, and does not feed into the blast-front overpressure, but becomes important for the development of quasi-static overpressure in enclosures. In this study, we assume a simple reaction rate to indicate whether the fuel/air mixture has reacted based on the temperature. The importance of the secondary reactions can be seen below in Figure 1.

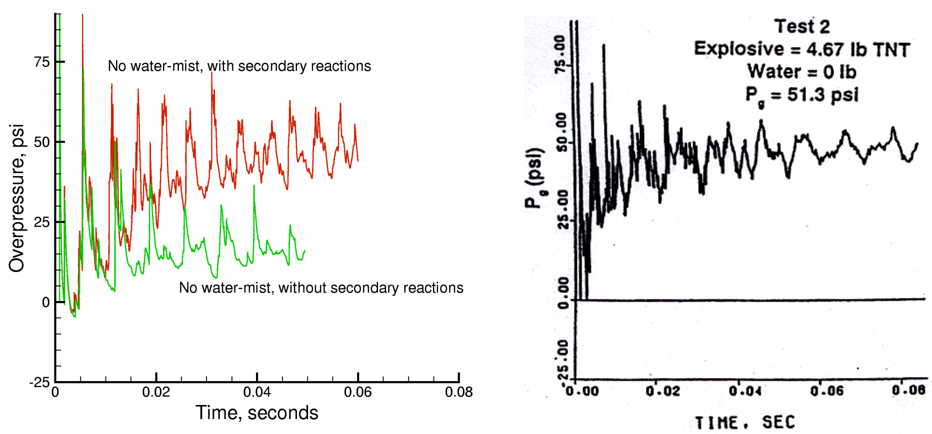

Figure 1. Pressure development comparison of simulation and NCEL tests (Keenan and Wager, 1992).

Because the secondary reactions are heavily dependent on mixing between the explosive gases and air, multi-dimensional simulations were required to obtain an accurate representation of the pressure buildup within an enclosure.

A series of two-dimensional computations were done to determine the effect of the water-mist on the development of the quasi-static pressure. For the simulations, 2.12 kg of TNT was placed in a cylindrical container 3.46 m long with a radius of 1.73 m, corresponding to a total volume of 32.5 m^3 which is very close to the volume used in the NCEL tests. Secondary reactions are accounted for using a two-step mechanism, reacting carbon dust to carbon monoxide and carbon monoxide to carbon dioxide. Reactions are assumed to be infinitely fast if the local temperature is above 600 K, and do not occur if the local temperature is below 600 K. Initially, 25-30 micron water-mist is spread evenly throughout the domain with a mass-loading of 0.5.

A representative solution is shown in Figure 2 at 1, 2, 5, and 15 ms after detonation of the explosive. From these pictures one can see the blast expanding from its initial location (bottom-right) early on, and then the picture gets more complex with the pressure waves reflecting and interacting continually. We also notice that the water-mist is pushed towards the outer walls, where it tends to stay as it evaporates. The secondary reactions, on the other hand, are occurring closer in towards the center of the domain, in the high temperature region away from the water-mist. Because of this, we infer that the water-mist does not directly suppress the secondary reactions, and that most of the mitigation seen for the quasi-static overpressure is from heat extraction due to vaporization. Even in the current simulations, without suppression of the secondary reactions , the mitigation of the overpressure is quite substantial, as is shown in Figure 3.

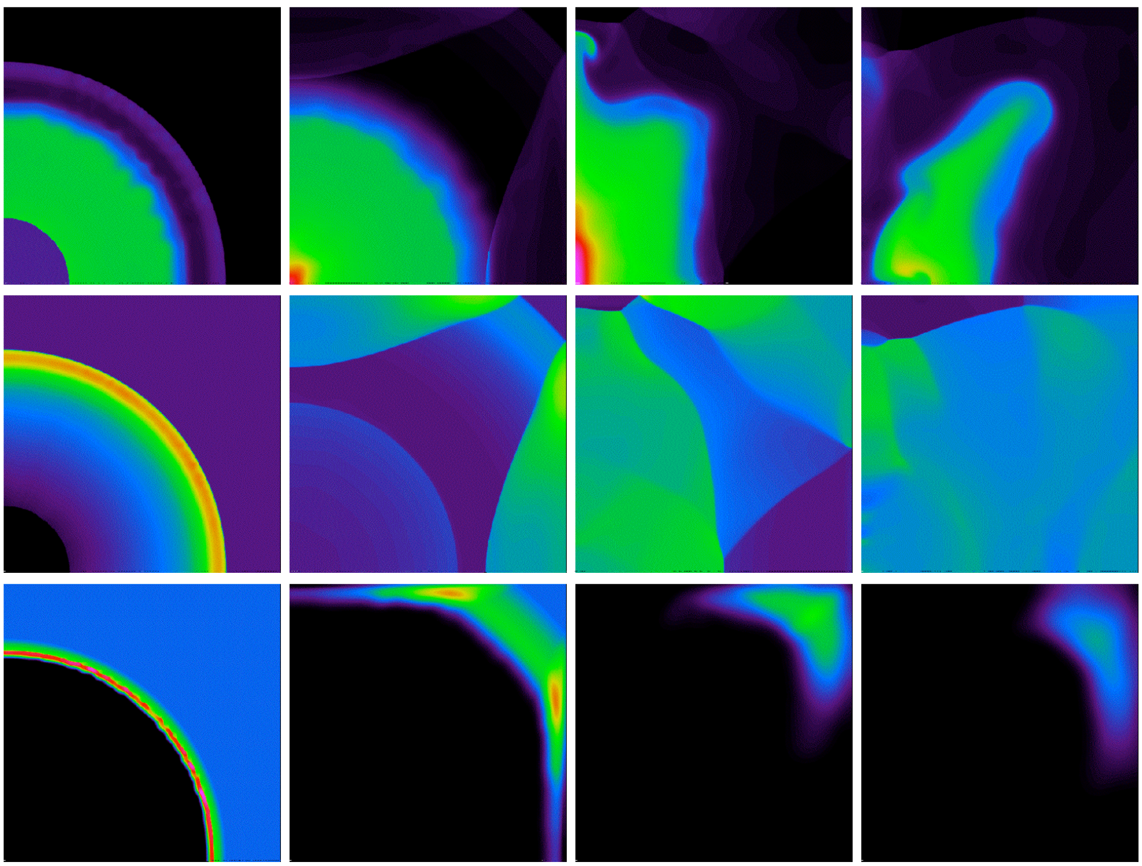

Figure 2. Temperature (top), pressure (middle), and water mist density (bottom) for one-quarter of the enclosure at 1, 2, 5, and 15 ms after detonation of the explosive in the presence of water mist. Temperature contour range is from 300 to 2500 K, pressure contour range is from 10^5 to $8x10^6$ dynes/cm^2. Water mist contour range is from 0 to 0.0025 g/cm^3.

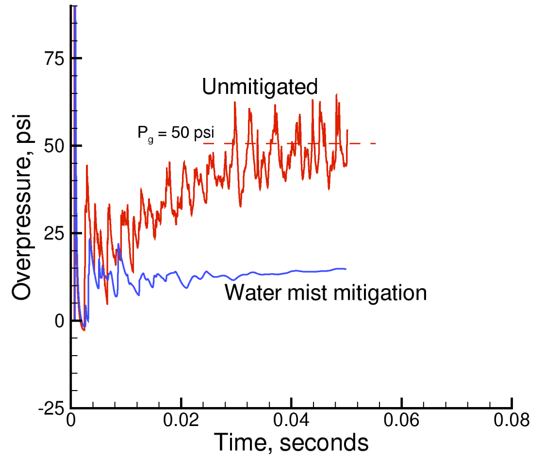

Figure 3. Comparison of NCEL computations with and without water mist.

Conclusion

Unsteady, multi-dimensional, multi-phase simulations were done to help study the effect of water-mist on spherically expanding blast waves and quasi-static pressure rise in enclosures subjected to blasts from explosives. The simulations found that for the configurations studied, suppression of the secondary reactions were minimal due to the water-mist being pushed towards the outer walls and the secondary reactions remaining in the interior domain. Even though suppression of the reactions was limited, overall reduction in the overpressure was found to be very good. This reduction is accomplished mainly through energy extraction from vaporization. These results are dependent on several variables, including explosive size and type, enclosure size, water-mist droplet size and mass-loading, and current simulations are attempting to understand the relationship between these different parameters.

Acknowledgments

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