Blast Overpressure Measurement for CFD Model Validation in the Development of Large Caliber Gun Systems

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This report discusses methods used and results obtained in the multiple phases of Blast Overpressure testing for the 120 MM XM360 Gun Assembly . It will be shown that techniques developed during arena testing led to refined methodology for the collection of specific Blast Overpressure data with regards to the test article. That data has and will be used to develop and analyze the effectiveness of competing cannon designs, to refine and validate Computational Fluid Dynamics models of large-caliber muzzle blast, and to reduce development time for vehicle hull design through valid simulation; all of which will be of great value to the overall development of the system.

Simulation Prior to Test

Throughout the last decade, modeling and simulation have become a vital tool for program managers to reduce risk and achieve savings in both cost and schedule. The ability to simulate both developmental and operational scenarios prior to a system's full-scale testing is integral to any development model and consistent with modern engineering best practices.

However, in order for simulation to be beneficial, items under test must be characterized, such that computer models accurately reflect the physical properties and performance of the components. This means understanding the blast overpressure signature both in the free space surrounding the muzzle and on the surface of the vehicle's hull. Figure 1 clearly shows the environment in which we are working.


Figure 1: Prototype cannon and muzzle blast from typical munitions.

Through Computational Fluid Dynamics (CFD) modeling, Benet Labs has begun to apply modern commercial codes, such as Fluent, to full vehicle and partial vehicle 3-D models to determine the effects of various cannon designs. In order to refine and validate these models, however, actual testing must be performed. Data gathered during that testing is compared to predicted values and new techniques are developed to improve accuracy. Output such as in Figure 2 aids the design engineer in determining the effectiveness of new designs.

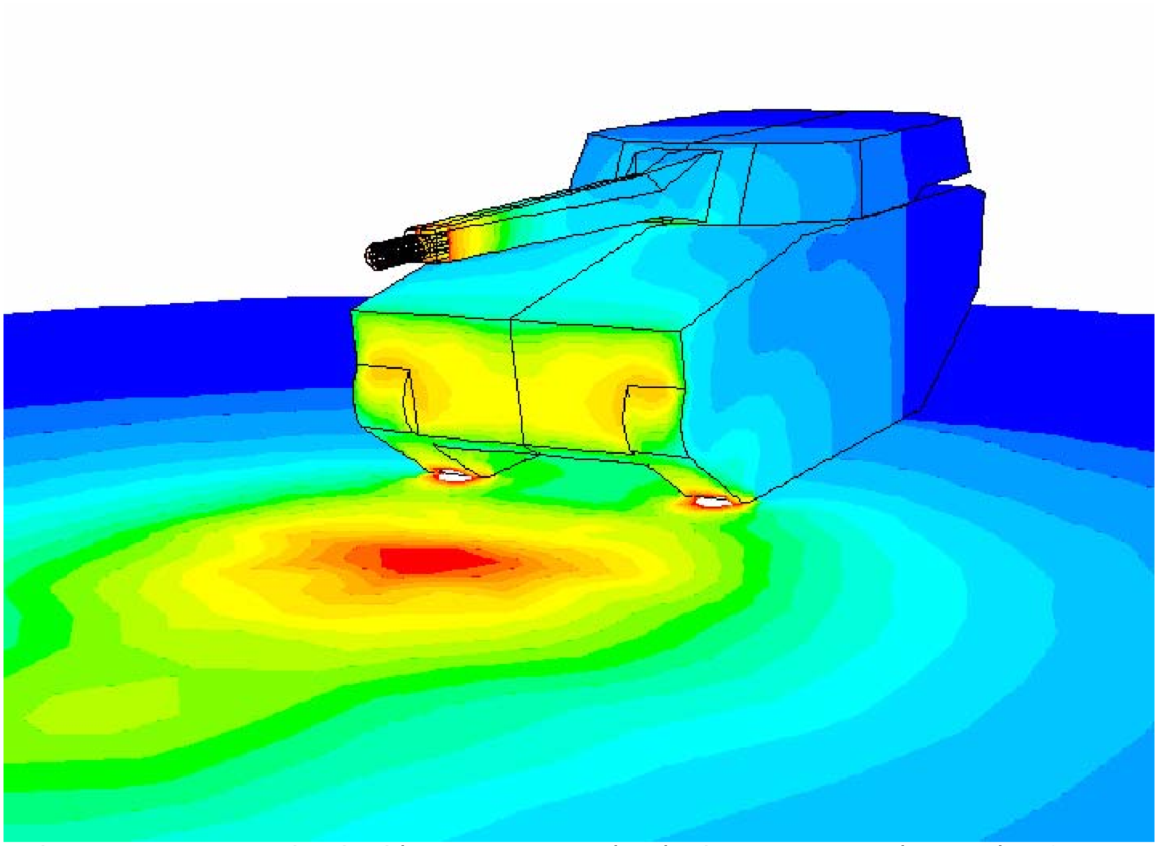

Figure 2: CFD output showing blast overpressure levels. (Courtesy: Dan Cler, et al., of Benet Labs)

<u>Free Field Blast Overpressure Measurement</u>

Prior testing, including a blast overpressure arena test, has shown that when the origin of blast is known, the preferred sensor geometry for incident (i.e. side-on) pressure is the “pencil” probe. This probe provides a clean surface such that the blast wave is able to travel smoothly across the sensor’s element, located flush on the top surface and set back several inches from the leading edge. Figure 3 shows this probe installed at the test range.

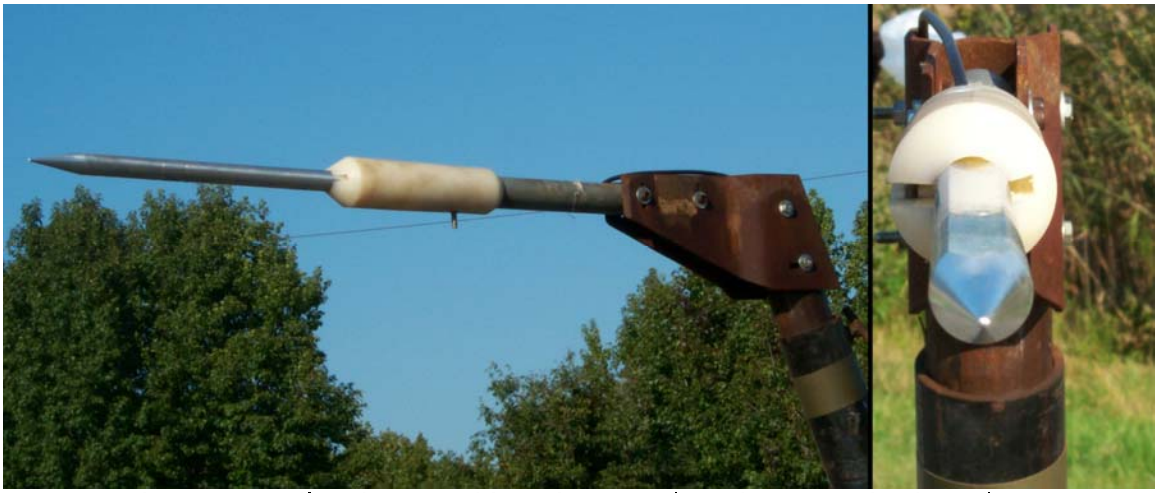
Figure 3: Pencil probe from side and front. Clamp is non-conductive nylon.

Figure 4 shows a typical blast overpressure signal, compared to the also common "blunt cylinder" geometry. It can be seen that the blunt cylinder produces a false peak compared to theoretical values. This mounting geometry has its benefits, however, particularly when the origin of blast is not well defined, or when multiple blast wave reflections are expected (environments such as the interior of a vehicle).

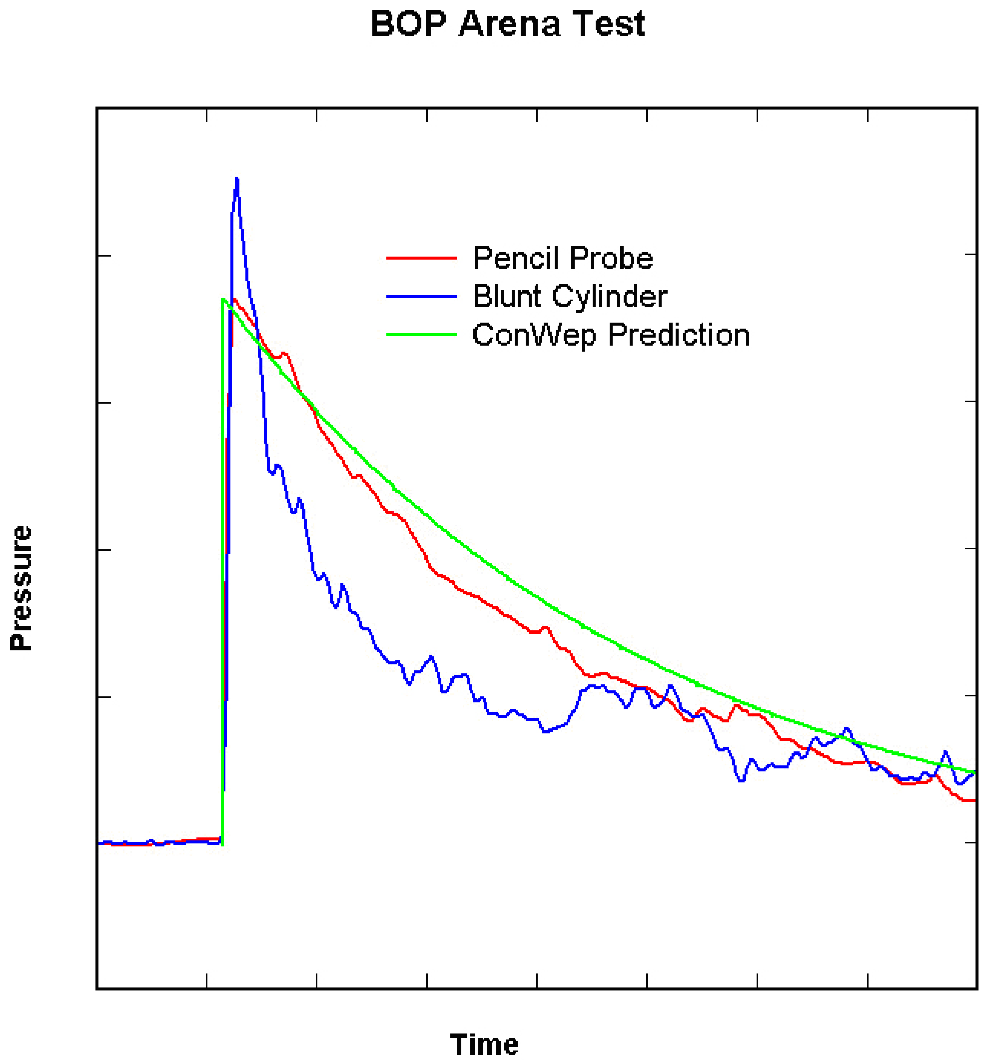

Figure 4: Arena testing supports pencil probe geometry for this style of measurement.

The next challenge is aiming these probes at the source of blast. With muzzle blast, the origin and free surface orientation of the blast wave front is not spherical as it is in arena testing. As a result, a rough approximation of the origin of the blast is just in front of the muzzle of the cannon. Because of this uncertainty in the direction of the blast wave, the probe angle may be off from 10 or more degrees as indicated from CFD modeling. Figure 5 shows the overall configuration of pencil probes with relation to the cannon.

Figure 5: Bird's eye view of sensor arrangement for free field BOP measurement.

The placement of sensors may be accomplished quite simply by an individual or a crew of two. Geodetic surveys mark spots on the ground above which the sensor should be located. These are in the form of nails driven into the asphalt and then circled with orange paint as can be seen in Figure 5.

Figures 6 and 7 show a plug that is inserted into the muzzle end, from which a length of filament (fishing line, piano wire, etc.) is strung. The filament is pulled taut between the muzzle and the farthest sensor location. Between the filament and a plumb bob, the sensors can be located to within an inch of their desired location, and oftentimes better.

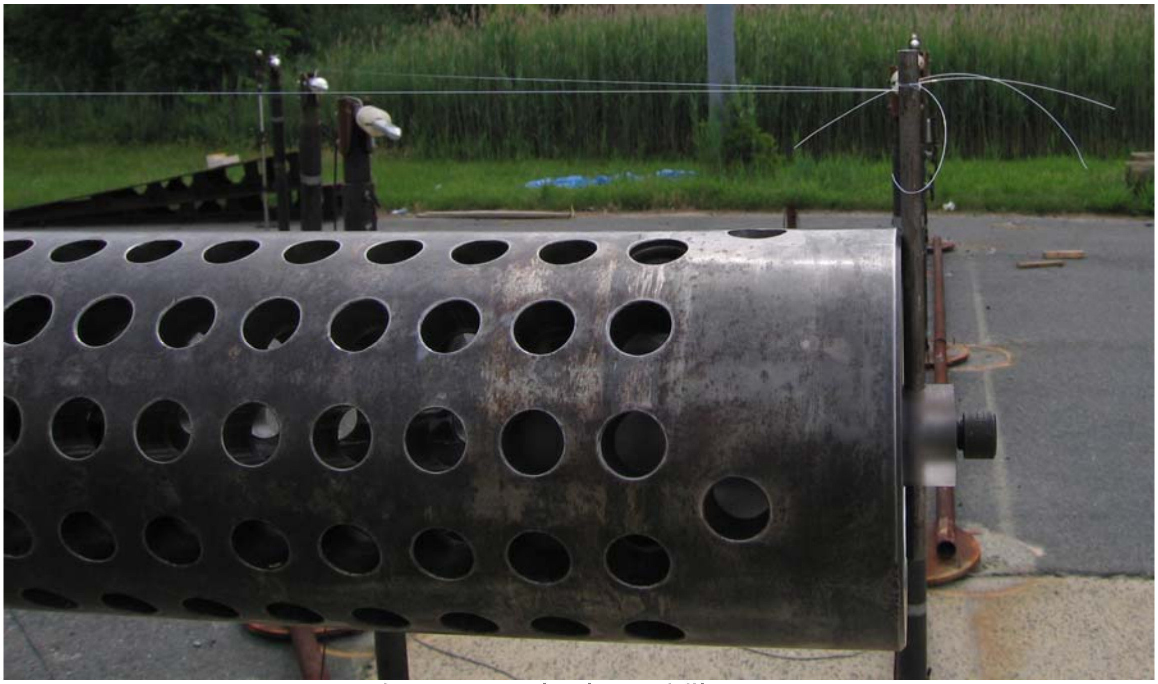

Figure 6: Muzzle plug and filament.

Figure 7: Looking down the filament to aid alignment of sensors.

It is worthy to note, however, that for CFD model validation, the sensors are not required to be perfectly spaced. Rather, it is far more important to know *where* they actually are. This is determined by follow-on geodetic surveys to confirm their locations and/or record discrepancies which can later be compensated for in the CFD model.

Data from the firing of various rounds indicates the accuracy of placement. Figure 8 is a typical pressure versus time plot generated by one “radius” of these pencil probes. Each sensor is located 12 feet from the muzzle, however the angle varies from 90° to 120° and then nearly 180° backwards. As expected, the first two sensors feel the blast wave first, and their timing is extremely close (within 0.095 msec). This level of accuracy helps the design engineer by providing a reliable measure of blast wave velocity. Additionally, peak levels are in close agreement. The third sensor is not hit with blast until approximately 0.75 msec later, as the blast must work its way out of the muzzle before turning backwards towards that position.

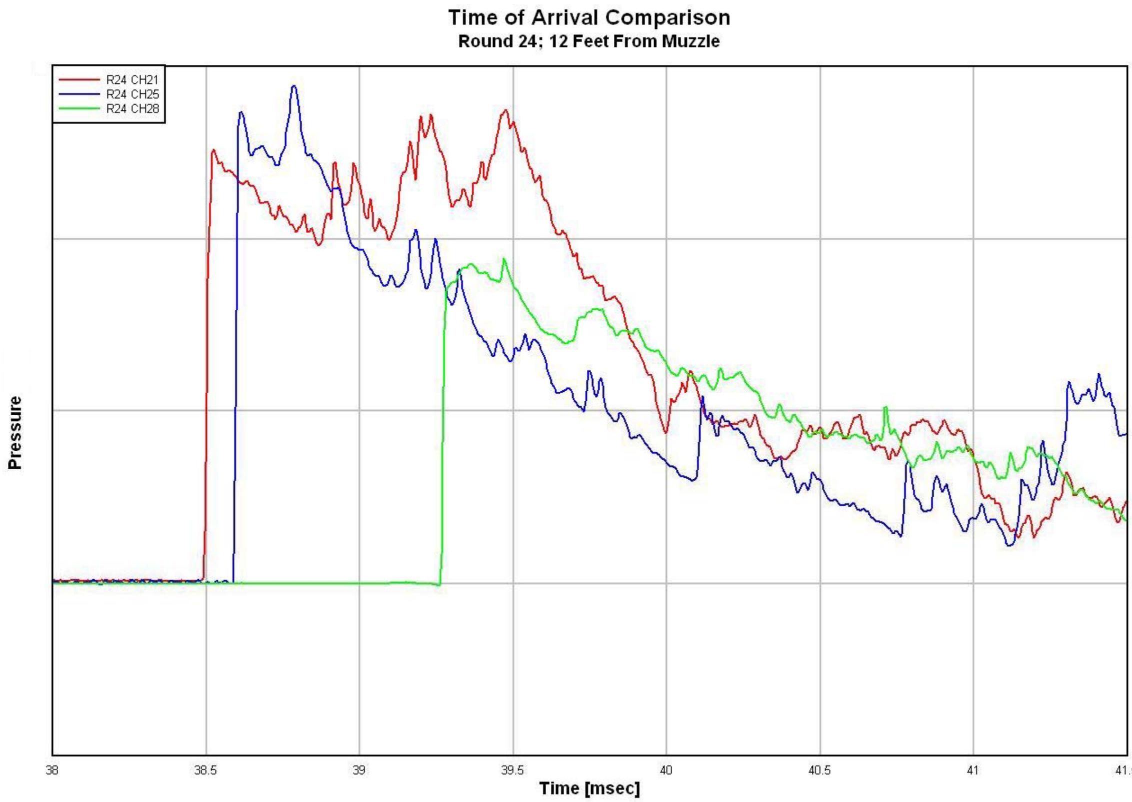

Figure 6: Time of arrival around 12 foot radius indicates accurate placement of sensors.

Moving out to the 40 foot radius, a similar relationship is observed. Figure 7 shows all four sensors record the blast wave arriving within 2 msec of each other. The two sensors closest to being perpendicular with the muzzle record blast wave arrival time within 0.34 msec.

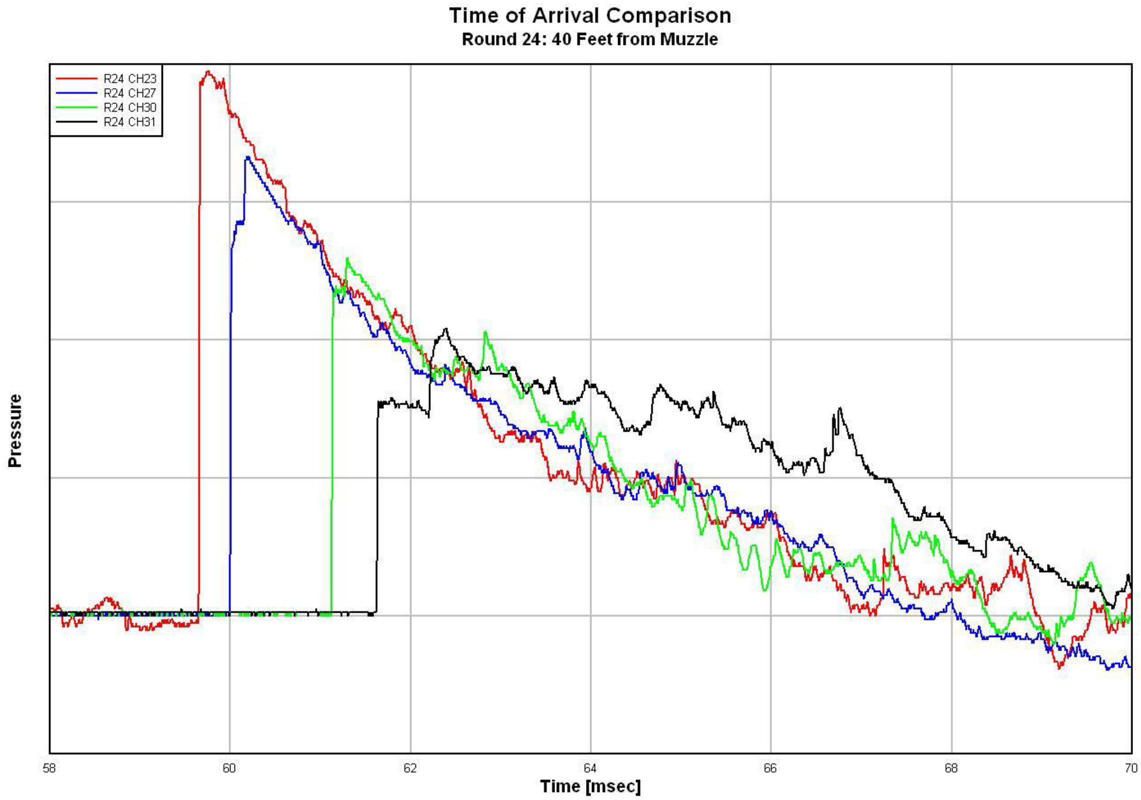

Figure 7: Time of arrival around 40 foot radius further indicates placement accuracy.

Finally, we may also look at a group of sensors along one “arm” of the free field array. Figure 8 shows the rate at which the blast wave decays with distance, as well as allowing the design engineer to calculate velocity and impulse.

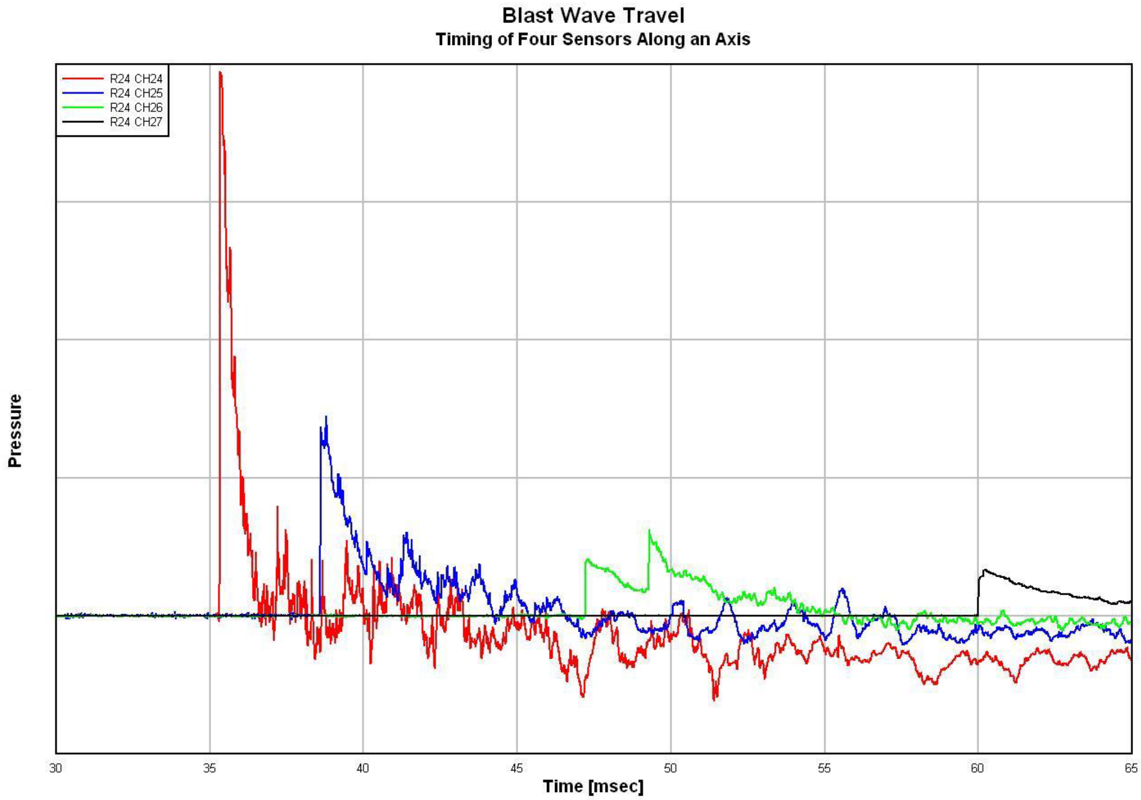

Figure 8: Blast wave travel along an arm of the free field sensor array.

Vehicle Hull Blast Overpressure Measurement

The next step in acquiring data for CFD model validation is determining what loading the blast overpressure applies to a proposed hull geometry. As opposed to the incident blast measurements made in the free-field, these measurement are reflected (i.e. face-on) or at some angle between side-on and face-on. A multitude of sensors were placed flush with the vehicle hull, as can be seen in Figure 9.


Figure 9: Hull mockup with blast overpressure sensor array.

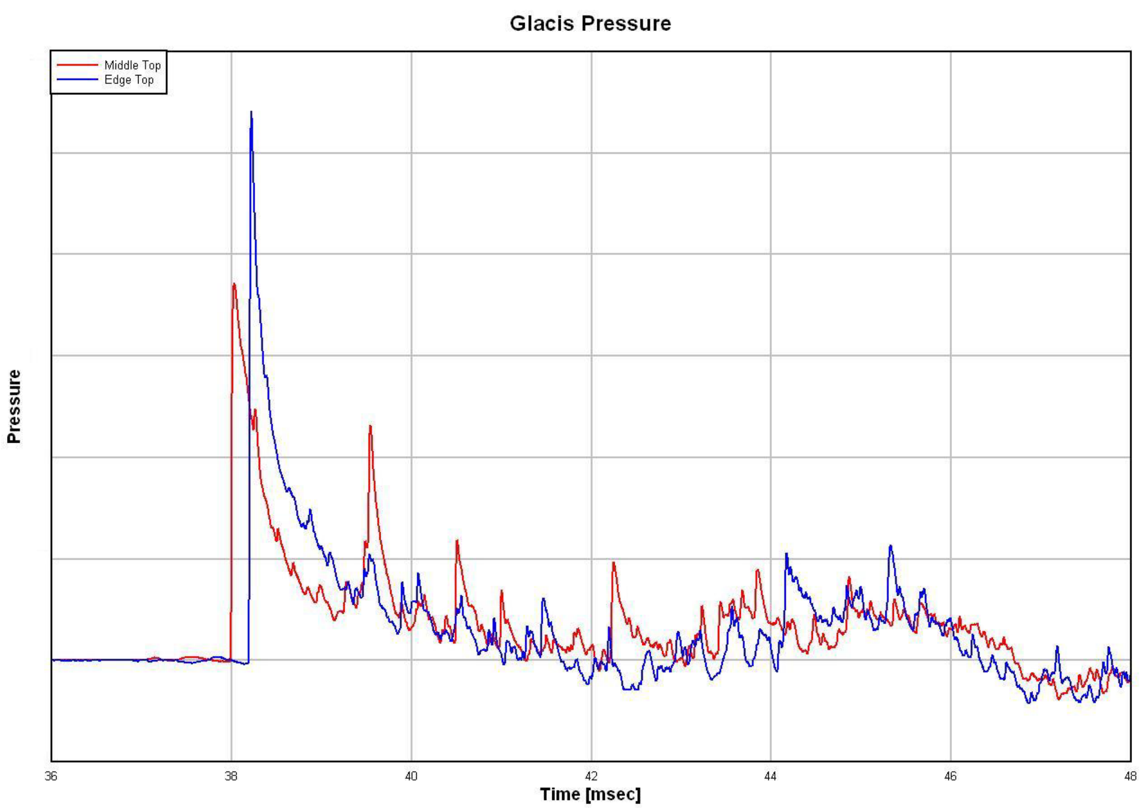

Figure 10: Pressure plot near middle on top, near edge on top.

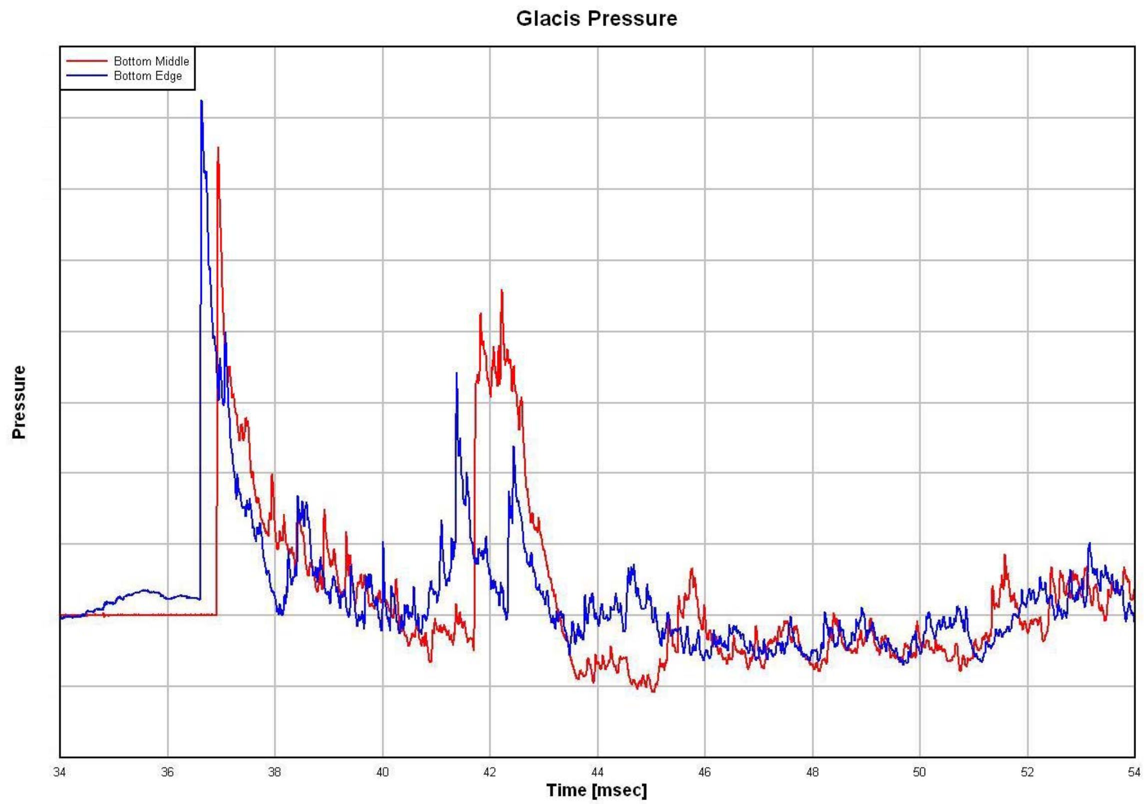

Figure 11: Pressure plot in front, showing higher peak due to ground reflection of blast.

It can be seen that there is a significant reflected pressure on the lower portion of the glacis. Therefore, it is advantageous to design cannon and vehicle hulls in conjunction, to reduce the damaging affects of this blast.

Conclusions

In summation, the techniques for blast overpressure measurement outlined here are the culmination of efforts made over two years of theory, trial and refinement. The requirements for accuracy and reliability associated with CFD model validation mandate this effort. Data acquired is and will continue to be used to develop models that in turn will drastically reduce cost and development time for future weapons systems.