Three dimensional hemispherical test development to evaluate detonation wave breakout

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Abstract. The Onionskin test has been the standard test to evaluate detonation wave breakout over a hemispherical surface for decades. It has been an effective test used in a variety of applications to qualify main charge materials, evaluate different boosters, and compare different detonators. It is not without its shortfalls however. It only images a small portion of the explosive and requires very precise alignment and camera requirements to make sense of the results. Asymmetry in explosive behavior cannot be pinpointed or evaluated effectively. We have developed a new diagnostic using fiber optics covering the surface of the explosive to yield a 3D representation of the detonation wave behavior. Precise timing mapping of the detonation over the hemispherical surface is generated which can be converted to detonation wave breakout behavior using Huygens’ wave reconstruction. This report will include the results of a recent suite of tests on PBX 9501, and discussion of how the test was developed for this explosive and contrasting previous work on PBX 9502. The results of these tests will describe the effects on detonation wave breakout symmetry when Sylgard 184 is placed between the detonator and booster. The effects on symmetry and timing when the Sylgard gap thickness is increased and the detonator is cant is will be shown.

1. Test Overview

Given inherent limitations in the onionskin test to evaluate asymmetrical behavior [1-4], a 3D representation of the entire surface was needed [5]. In the Onionskin configuration, the camera uses a narrow slit which causes the bulk of the surface to be obscured (figure 1). The test we developed, called the “Furball,” uses fiber optics arrayed over the surface and oriented into a planar surface, which is then imaged with the streak camera (figure 2). The arrival of light is used to measure detonation wave properties and timing. Previous Furball tests were conducted using PBX 9502, which required the use of paint to create a flash for imaging purposes [6,7]. It was expected PBX 9501 would supply more light, possibly oversaturating the streak image so care was taken to evaluate this effect before proceeding to the tests. Several practice shots were conducted to evaluate light saturation, fiber optic image edge sharpness, fiber optic material choice, and fiber optic end treatment. The final shot configuration was chosen to optimize the quality of the streak image.

Figure 3 shows the results from a practice shot where fiber end treatment was evaluated. The goal of the shot was to minimize prelight and demonstrate a sharp edge on leading fiber optic on the streak image. Prelight was a significant issue with uncoated fibers. Because the fibers are arranged in rows with a separation of less than 1 cm, the long tails associated with each fiber needed minimization as well to avoid overwriting data on the streak image. The fiber end treatment was chosen to eliminate prelight, cause the light flash to assume a largely circular shape and minimize the existence of long tails, avoiding the overwriting of data. The circular shape maintained the same size and geometry of
the fiber seen in the still image. The holes associated with each row were staggered so overwriting data was not an issue.

![Image of fiber and still image](image_url)

**Figure 1.** Onionskin test viewed from pole. Mirrors on the sides image equator (left image). Streak camera slit prevents bulk of real estate from being viewed (right image). The resulting streak image is shown on the lower right.

![Image of fiber optics and streak record](image_url)

**Figure 2.** Fiber optics are arrayed over surface of hemispherical charge (left). Fibers are raced to plane imaged by streak camera (right). Bent rod drops resulting fireball out of viewing plane.

![Image of fiber end treatment tests](image_url)

**Figure 3.** Fiber end treatment tests: the top row is coated with aluminum, the bottom row is uncoated. Prelight is a significant problem with uncoated fibers as evidenced by the leading edge, which makes exact time of arrival difficult to pinpoint.

For timing purposes, the shot included a fiducial detonator to establish time zero. This represents the time when the detonator initiates, and is expected to be largely identical to the detonator in the shot itself. Four fiber optics are oriented on the fiducial. On the streak record the light associated with these points represents time zero and relative time from these points to the first line of fiber data represents the amount of time the detonation takes to traverse the charge and breakout on the surface.
Time data for each point relative to where it was originally located is collected and used to evaluate the temporal 3D response of the experiment.

Gaps of Sylgard 184 were included to see the overall effect on the surface breakout. Shims of appropriate thickness were used to create the gap space around the detonator well, filling the well with Sylgard and inserting the detonator until it was resting on the shims. Placing shims of different thicknesses on either side of the detonator well made canted gaps.

Two practice shots were fired to evaluate shot design and lighting. Fibers were glued in place using super glue. The glue wicked into the holes and down to the HE surface. This was not ideal, when the streak data was found to be compromised in clarity. The glue was changed to Barco Bond, which did not wick into fiber holes, and the streak image was improved. The fibers were polished flat and coated with aluminium (shot 1) or silver paint (shot 2). Neither coating worked well. Angled fiber ends were chosen to mitigate these lighting issues. A rod was used to connect the viewing plane to the shot itself. Shot 1 used a straight rod, which unfortunately put the HE in the same plane as the camera image plane. This caused excessive lighting from the resulting fireball. Shot 2 used an angled rod, which dropped the HE out of the viewing plane and mitigated fireball lighting issues (figure 2).

2. Results
A total of 9 shots were fired, this included two practice shots, which were not analyzed because of shortcomings in the streak records. Table 1 describes the tests conducted. Time to first break out (TBO) describes the elapsed time from the fiducial detonator initiating to the earliest break out on the surface of the main charge. It represents the shortest amount of time the wave takes to traverse the hemisphere. First break out angle (FBA) describes the radial angle, which corresponds to the shortest elapsed time. Total breakout time (TBT) represents the amount of time from the first breakout until the entire main charge is consumed.
Table 1. Experimental series results. TBO is Time to BreakOut, FBA is First Breakout Angle, and TBT is Total Breakout Time.

| Shot # | Configuration       | TBO  | FBA  | TBT  | Details                                                                 |
|--------|---------------------|------|------|------|--------------------------------------------------------------------------|
| 3      | Baseline #1 (no gap)| 1.33 | 0°   | 360  | Time ns<br>Pole. Angled Fiber ends. Barco Bond. U-shaped streak data     |
| 4      | Baseline #1 (no gap)| 1.32 | 0°   | 380  | Same as shot 3.                                                          |
| 5      | 5 mil Sylgard gap   | 1.40 | 10°  | 327  | Time ns<br>Flatter U-shaped streak                                      |
| 6      | 15 mil Sylgard gap  | 1.55 | 55°  | 267  | W-shaped streak                                                          |
| 7      | 50 mil Sylgard gap  | 1.59 | 70°  | 294  | W-shaped streak                                                          |
| 8      | Thick canted gap    | 1.53 | 60°  | 250  | 12 mil thick one side, 17 mil thick other side. W-shaped streak          |
| 9      | Thin canted gap     | 1.41 | 0-15°| 345  | 3 mil thick one side, 8 mil thick other side. W-shaped streak           |

Figure 5. Shots investigating PBX 9501 breakout. Comparison of shots’ streak data (bottom image) and results of visualization tool (top image). Red designates early time, blue late time. Darkest red is the location of First Breakout (FBO and FBA). Shot 3 was a baseline shot with no Sylgard gap. Shot 8 was a thick canted shot with a Sylgard gap 12 mil on one side, 17 mil on the other. Shot 7 is a 50 mil gap. Each line in the streak image represents a bisecting line of points from equator to equator through the pole. It can be visualized as six onionskins, each one separated by 30 degrees.
Data analysis from the streak image involves finding how far each point moved in time relative to its starting position. Selection of where to measure each point from can skew the data slightly, and the error associated with each time measurement is ±2 pixels, which translates to approximately ±2ns.

Observing the changes in TBO, FBA and TBT with gap thickness reveal some interesting trends (figures 4 and 5). The baseline shots demonstrate timing associated with the charge in its intended configuration. The time required to corner turn and consume the shot is the greatest of any of the shots fired. The U-shape of the breakout behavior is indicative of a Conventional High Explosive (CHE) and this trend can be clearly seen in the streak image of figure 5, shot 3. The fact that it breaks out first at the pole is related to the shape of the charge where the shortest distance is from the center of the detonator to the pole and the shock supplied from the detonator would run-up to steady state detonation in the normal direction most ably. More interesting aspects arise when the inert gap is placed between the detonator and the HE. A thin gap (shot 5 and 9) takes longer to first break out, but maintains the U-shape of CHE breakout behavior. The thin gap of Sylgard does effectively retard the detonation of the HE, somewhat, and flattens the first breakout angle to a larger area, but retarding the detonation in the normal direction allows the side lighting to “catch up” slightly and the total time for the whole charge to be consumed is reduced. Further thickening of the Sylgard gap (shot 8 streak image from figure 5) dramatically affect the breakout shape to a W, suggestive of wave shapes seen in Insensitive High Explosives (IHEs). The thicker Sylgard effectively retards the wave in the normal direction and the wave propagates more easily to the side first. The total time is dramatically reduced, with consumption of the entire charge occurring in a significantly smaller time. The breakout wave is flatter and the FBA occurs over a large area. This is arguably a more efficient way to initiate the main charge. A very thick gap (Shot 7) slows the center down significantly. Side lighting is the prevalent mechanism for initiating the main charge. All shots are plotted together in figure 5, clearly demonstrating the timing changes with gap thickness. While this reduces a 3D image to 2D, it allows easy comparison. It can be seen how side lighting is largely identical despite gap thickness. The time retardation due to gap thickness can be seen. The flat breakout wave of shot 8 is a very interesting result. A more effective visualization tool was developed allowing a temporal representation on the hemisphere (figure 5). Red signifies early time, blue late time.

3. Conclusions
Comparison of the Onionskin data and the Furball data can be seen in figure 4, and the 3D visual representation in figure 5. The agreement between the two styles of shots is extremely favorable and the fact that given diagnostic differences, similar responses are observed lends credence to this test series. The gap thickness effects are real and reproducible. The capacity, with a relatively simple diagnostic to image a 3D phenomenon over an entire hemispherical surface is extremely valuable.

References
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