U.S. DEPARTMENT OF ENERGY
Sandia National Laboratories
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Hill AFB Test Plan February-March 2018

Introduction

This document will outline the test plans for the Hill AFB Mk 84 aging studies. The goal of the test series is to measure early case expansion velocities, sample the fragment field at various locations, and measure the overall shockwave and large fragment trajectories. This will be accomplished with 3 imaging systems as outlined in the sections below. The overall test view is shown in Figure 1 for all three systems. This drawing is approximately to scale.

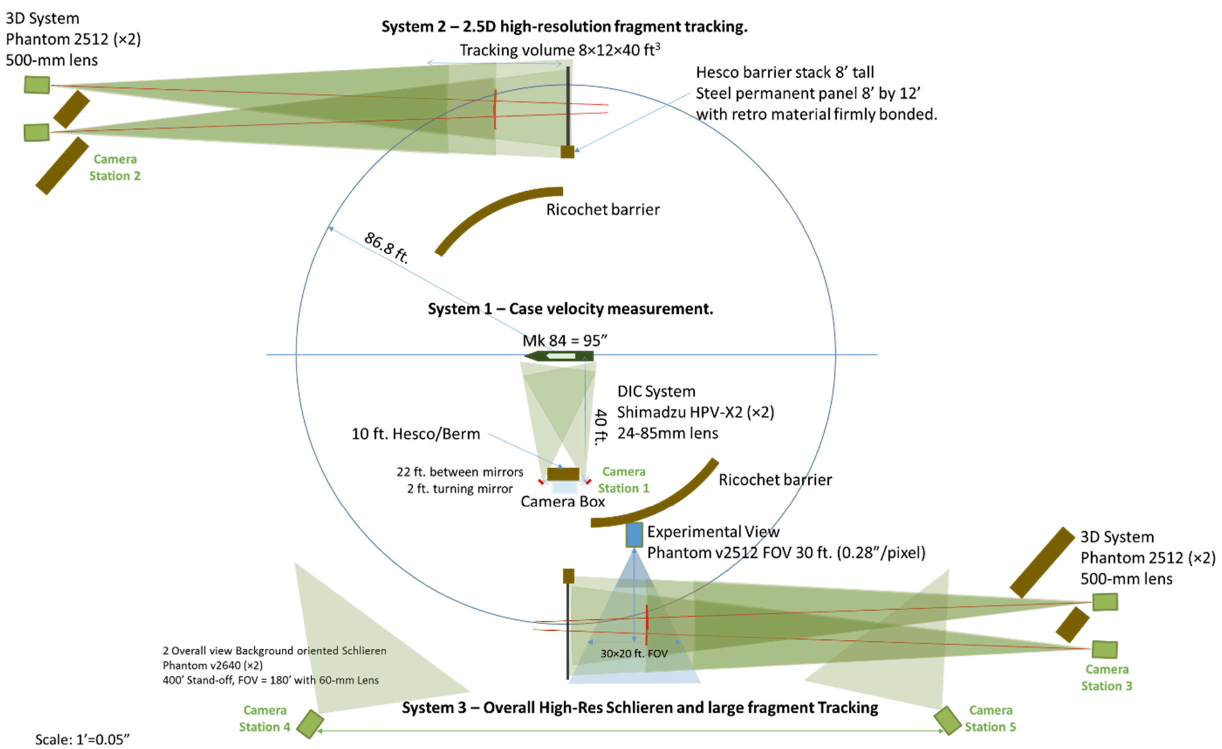

Figure 1. Test layout (approximately to scale) for the three test systems.

Test Range Setup and Infrastructure

As shown in Figure 1 there are 5 camera stations that will need to be located and built. The camera stations will need UPS power and network connections back to the test bunker. Cameras will need fragment protection provided by either berms or Hesco barriers. Overpressure protection will be provided by Sandia camera boxes for Stations 2-5. Camera station 1 will be built by Hill to Sandia design. Details of camera station design can be discussed with Hill as the site is being constructed. Items to purchase and rental quotes will be forwarded by Sandia as they are received.

Testing Series Scheduling

It is highly desirable that two test campaigns be associated with this long test series (≈20 bombs). One week of setup with Sandia personnel will be required before the first test series (Week 1). The one week of setup is assuming that the range has been assembled by Hill with camera stations, berms, Hesco barriers and other range setting has been completed before arrival of Sandia personnel. The first test series will progress at a slower rate, optimistically one test every other day, for a total of 3 tests (Week 2). This will allow all personnel to ring out range and camera station issues and optimize the setup. Data will be able to be quickly viewed after the test and preliminary data analysis will guide optimization of the experimental setup. After the first test series, a one week break will occur for a deeper look at the first 3 test data sets (Week 3). This will allow any further modifications to be made to either the test setup or test process. After final optimization of the experimental setup, the remaining weeks will be data collection at a rate of 2 tests/day.

Schedule
Shock testing and DIC survivability test.
Week 1 (Calibration Shots) – Experimental Setup of the cameras on the already completed range.
Week 2 – Ring down test series of three tests.
Week 3 – Data analysis week – no testing.
Week 4 and following – Testing of remaining bombs at 2/day.

System 1 – Case Velocity Measurement using DIC

Measurement Goal

The goal of System 1 is to measure the full-field case velocity at many points (1000's) distributed along the case. The primary measurement will cover about 20˚ of the case cylinder that will be visible from the camera setup (see Figure 2). A stretch goal is to place a mirror below the bomb to provide another wedge of velocity measurements on the bottom of the case.

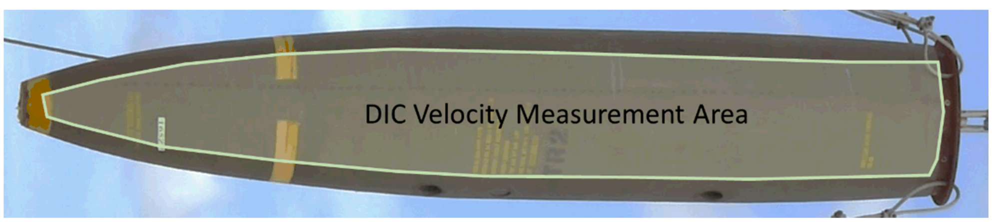

Figure 2. Approximate DIC case velocity measurement region.

A risk to successful DIC measurements include too much light break out from the tail as the case comes apart. This will likely most strongly effect the last portions of the case destruction. It may be necessary as noted below to explore other lighting options.

Cameras will be rented by Hill. A quote has been obtained for camera.

Setup Description

Two synchronized Shimadzu HPVX-2 Cameras will be protected in a hardened box behind dirt embankments (Hesco barriers or berms). The cameras will look out both ends of the box at two turning mirrors placed about 22 feet apart. The cameras will be approximately 40 feet from the bomb for a stereo-angle of 25 degrees. The turning mirrors will be disposable and replaced between each shot. To view the entire bomb at one time will require a field-of-view of 95-inches and a lens of 80-mm focal length. The Shimadzu camera yields only 75 pixels across the surface, which is marginal for tracking points. However, due to the better light sensitivity and the better image quality, particularly when the detector is light saturated, the Shimadzu is the optimum camera choice for this series of experiments.

Because UHS cameras maintain their pixel count in both directions at all frame rates, and due to the very narrow aspect ratio of the bomb, there are many pixels on each side of the bomb that are not used. As a possible stretch goal, 6×3 foot mirrors could be placed below the bomb to image a second surface. These mirrors are relatively inexpensive and would be expendable in the test. A wooden frame to hold the bomb, and the two mirrors in position will be cheaply prefabricated from wood before the tests.

The box has been designed by Sandia, but the building and siting of the protective box behind the berm will be done by Hill. The wooden bomb stand is currently being designed by Sandia. These will need to be made before test time.

Lighting

Lighting will be done with Luxeon Star 7-LED Lime green LED arrays. These will be made by Sandia and brought with us to the test. Lights are continuous on and will be switched on and off pre-test by ethernet power switches. The 12 LED arrays will be mounted in a circle around the viewport hole to align the lights with the camera optical axis. A prototype is shown in Figure 3. Light location is important to ensure the best return from the retro-material. The LED array will need to be housed in a hardened case to prevent damage from shock and overpressure. This has yet to be designed. Retro material on the bomb will either be painted on or applied via a peel and stick method. Speckle application must be an easy operation because of the number of tests. The peel and stick material provides better light return, however, there may be some questions to how well it is bonded to the bomb relative to the paint. We will investigate this during the first test series. However, due to ease of application may be the preferred option. Lab testing has shown that even with 6 LED arrays we are able to run at 500,000 fps with the Shimadzu cameras. The lighting will be mounted in cases outside the camera bunker in hardened cases. Design work still needs to be done to finalize this system, including adequate pressure protection without too much loss of light.

Figure 3. Prototype DIC LED lighting.

We are attempting notch filtering using bandpass filters designed for LEDs at the wavelength of the LED arrays. Unfortunately, preliminary testing indicated that the bandpass may not reduce the broad illumination enough to improve the image quality. Regardless, we will use this and see if it helps.

A fallback lighting position of using flash lamps mounted at the case will be tested and ready to go if needed on sight. This is not a preferred option as the setup is more involved and the cost is higher per test to replace the one-time use flash lamps.

Lights will be supplied by Sandia.

System 2 – Fragment size and velocity measurements

This system is based on our well-tested 3D fragment two camera system. This uses two high-speed cameras setup with a FOV 12×8 feet, with a depth of about 40 feet. Sandia's 3D fragment tracking system has now been fielded twice in large scale field operations. It has proven itself to be robust. The technique works by using two cameras with a narrow stereo angle (6-9 degrees) that provide a large overlapping FOV. This optimizes the measurement volume to capture as many fragments as possible using the large depth-of-field (DOF) of a long focal length lens and simplifies camera setup by keeping the cameras relatively close together. A 500-mm lens will be used which provides a FOV of 12×8' at 180-foot standoff with a 40' DOF. This provides a measurement volume of approximately 12×8×40 feet^3 (see Figure 1). This FOV is dictated by the minimum fragment size and velocity to be measured. This FOV will provide a minimum measurable fragment size of ¼" in size. Previous testing seems to indicate this is an appropriate minimum fragment size to target. Figure 4 shows the results for 70 fragments tracked for System C at the 2017 Eglin test. The measurement volume achieved by System C is shown in Figure 5 and indicates a practical measurement volume of 12×8×70 feet^3 – yielding about 70 total fragments in the volume. Each blue dot is a hand tracked location in the measurement volume. Each of the 70 fragments was tracked at 5 frames in the measurement volume.

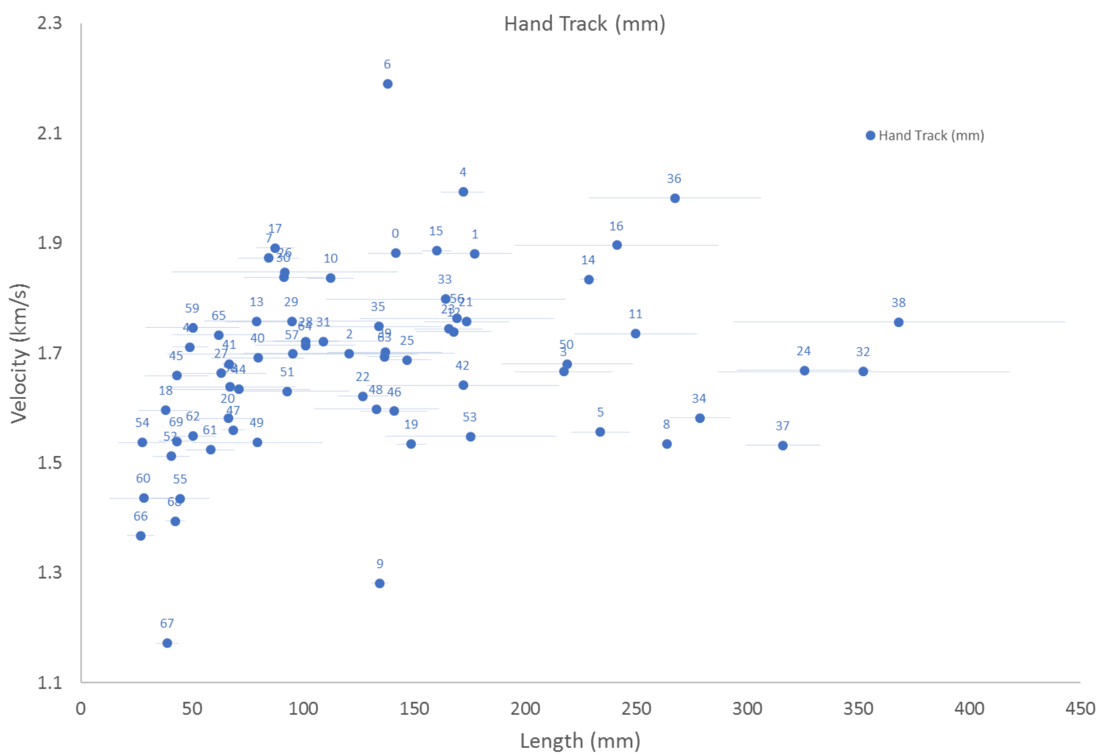

Figure 4. Eglin System C hand track Fragment Size versus Velocity. Error bars are 1σ estimation in length error.

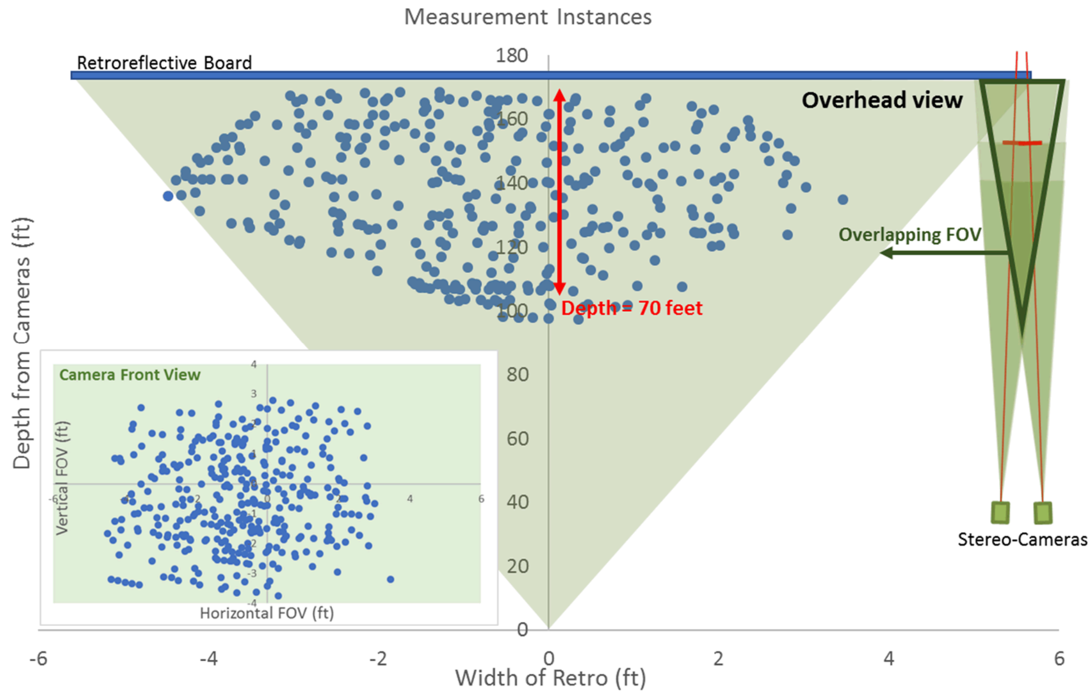

Figure 5. Fragment volume measured at Eglin System C

The lighting will be done using the Marine Beam focused LED light array with a retroreflective board (as used at the Eglin 2017 test). This creates exposures in the 2 µs range (System C at Eglin) and is inexpensive and robust. The retroreflective board will be approximately 12×16-ft^2 square and located at the diameter of the traditional Celotex capture location (see Figure 1). Based on the nature of the fragmentation "beam spray", two tracking systems may be placed at different locations to capture the effect of the void on case fragmentation. While moving these systems is possible – due to the construction of the retroreflective wall and camera protection, it would be best if these were semi-permanent installations for this test series. A decision as to the location of the systems must be made soon. Previous tests have used plywood and 2×4 construction that held up well for a single test. Two wall approaches are possible. First, we could construct temporary wood walls that would need to be regularly replaced (most likely for each test). Cost per wall is approximately $400. A second approach would use a more robust steel wall that does not need to be replaced on every test. It is uncertain whether this wall would be able to survive a test – but if it were able to, this would maybe be a cheaper option. Failure of the panel occurred because of blast pressure ripping the structure apart and negative pressure sucking the retro-material off the surface. Preliminary ideas include a metal panel shielded from fragments by Hesco barriers. The panel will be firmly fixed into the ground and robust enough such that it will survive the pressure loading of the bomb. Steel beam and plate construction are envisioned. Survival of the retro-material between tests is of some concern. Some research will need to be done to ensure optimum bonding of the material to the metal panel. Different vendor supplied retro-materials have been optimized for different surfaces. At this point we have not been using an optimized material on a surface it was designed to bond to. It is hoped that with the correct backboard material (metal) and greater care in surface preparation and bonding, the material can survive the negative pressure loading. If there are some small areas of damage they may be repaired by pasting new retroreflective material over the damaged section.

Note: Building of the retroreflective walls (wood or steel) will be done by Hill. Design ideas will be supplied by Sandia.

Camera protection

Sandia will provide camera boxes that have been previously used at the Eglin test for both the fragment tracking (System 2), experimental camera, and Schlieren camera (System 3) protection (7 boxes total). These may be used for the entire March test duration by Hill AFB. At the end of testing the boxes will be returned to Sandia, and an improved model design will be supplied to Hill to manufacture their own camera protection.

Improved Uncertainty

The uncertainty of the fragment size is larger than desired as shown in Figure 4. This is due to the lack of rotation of the fragments as they traverse the FOV and the narrow stereo angle of the cameras. The narrow stereo angle was chosen to optimize the number of fragments captured per system for these rather sparse fragment fields (e.g. only 70 fragments in the 12×8×70 $feet^3$ measurement volume). The lack of rotation results in fragments that are poorly oriented and remain poorly oriented to the cameras and do not provide a good cross-sectional view of the fragment. This precludes the use of 2D sizing of the fragment, and 3D triangulation was done to measure the size more accurately. However, the combination of determining the top and bottom point correspondences of a fragment for triangulation and the larger uncertainty in the narrow stereo-angle triangulation leads to larger errors. To improve the size estimation of the fragments, different camera options will be explored in various tests as time allows during the extended test series. The first attempted improvement will be the placement of a perpendicular camera (see Figure 1 – blue camera) that overlaps 40 feet of the measurement volume. This will provide a perpendicular view of the fragments that will improve the size estimation of poorly oriented fragments in the stereo view and decrease the size uncertainty. The perpendicular camera will be buried behind the berm and use the sky as a background.

Extra cameras will be supplied by Sandia.

System 3 – High-resolution Schlieren and Large Fragment Tracking

System 3 will use two of Phantom's newest high-resolution high-frame rate v2640 cameras to capture the overall view of the explosive device. Results like those shown in Figure 6 will be produced. The cameras will be placed at approximately 400' in camera protection boxes and use a mirror to view the event.

Large fragments have been successfully tracked using these large overall views. Approximate measurable fragment size versus FOV estimates are listed in Table 1. The second camera will be located at a 30-degree stereo-angle for an attempt at corresponding and triangulating the large fragments. Location of these cameras relative to the bomb needs to be determined. Locations in Figure 1 are notional.

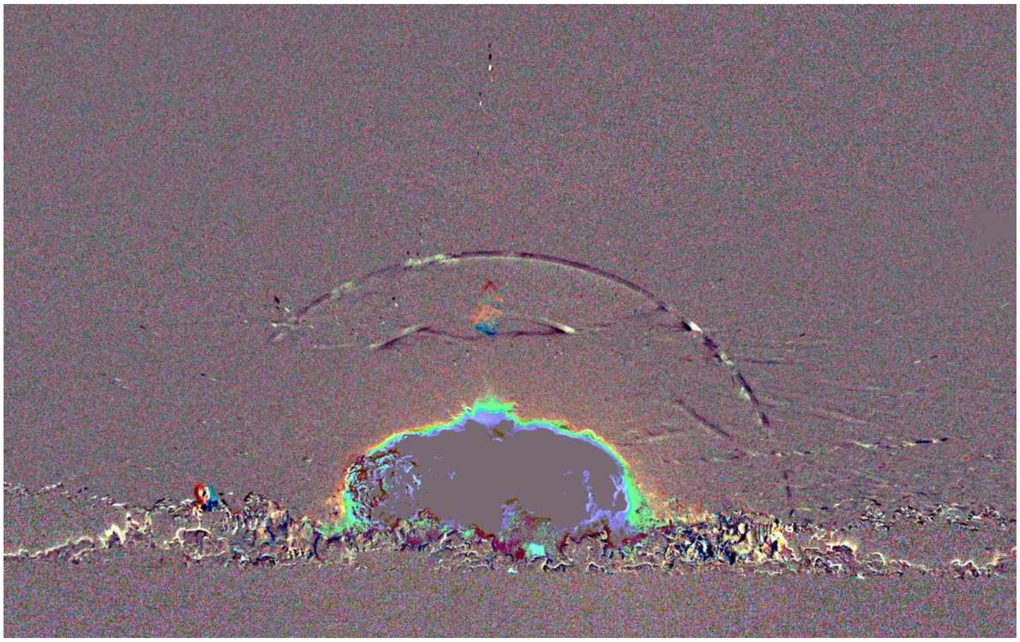

Figure 6. Schlieren image taken from Eglin 2017 overall view cameras.

Table 1. Fragment size table. Assumption: 5 pixels across fragment, 2 km/s velocity

FOV (M×M)	PIXEL SIZE (MM/PIXEL)	MIN. FRAG. SIZE (MM)	MIN. FRAG. SIZE(IN)	MIN. EXP. (MS)
1	0.78	3.91	0.15	0.39
2	1.56	7.81	0.31	0.78
4	3.13	15.63	0.62	1.56
10	7.81	39.06	1.54	3.91
15	11.72	58.59	2.31	5.86
20	15.63	78.13	3.08	7.81
30	23.44	117.19	4.61	11.72
40	31.25	156.25	6.15	15.63
50	39.06	195.31	7.69	19.53
60	46.88	234.38	9.23	23.44
70	54.69	273.44	10.77	27.34
80	62.50	312.50	12.30	31.25
90	70.31	351.56	13.84	35.16
100	78.13	390.63	15.38	39.06

Camera Stations

Camera stations will be semi-permanent installations. These ideas are preliminary design ideas that will need modification. Some of these are required and some are nice to have.

Each camera station will have the following:

1. AC Power with uninterruptible power backup.
2. Network connection (to control bunker)
3. 3-5 high-quality BNC cable runs (to control bunker)
4. IRIG connection.