Gas Pressure Testing Program and Measured Gas Pressure Histories

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Abstract

This paper describes a large testing program funded by the Department of Defense (DoD) Explosive Safety Board (DDESB) to measure the gas pressure history from internal detonations. Testing focused on test rooms with low loading densities and lightweight vent panels covering one or two full exterior wall and/or roof areas. During Phase 1, gas pressures were measured using special gas pressure gages, but the response times of those gages were too slow compared to the relatively short duration of the gas pressures due to large vent areas. In Phase 2 of the project, gas pressures were measured using standard piezoelectric blast gauges including baseline tests with no gas pressure. The measurement approach and measured gas pressure histories recorded in Phase 2 are discussed in this paper.

Introduction

UFC 3-340-02 (DoD, 2014) has separate simplified methods for calculating the shock pressure history and the gas, or quasistatic pressure history on the surfaces of a room with an internal detonation. These two parts of the internal blast pressure are caused by different physical phenomena and thus are calculated using separate methodologies. This paper describes a test program to measure the gas pressure history in the detonation room, which develops slower than the shock pressure. The gas pressure is caused by confinement of the heat and product gases from the explosion within the volume of the detonation room. The measured gas pressure histories discussed in this paper were used to help develop an improved fast-running method to calculate the gas pressure history from internal detonations for the DDESB. All testing was conducted by Applied Research Associates as a subcontractor to the Defense Threat Reduction Agency in the DoD and funded by the DoD Explosive Safety Board.

Measurement of Quastatic Pressure Histories

A total of 47 tests were conducted where high explosive charges were detonated inside a one room test structure with a lightweight panel covering either one or two full surfaces and rigid surfaces on the other sides of the structure. These tests are designated as the “vented” tests. Six fully confined tests were also conducted with rigid surfaces on all sides of the test room. Special gages used in the past to directly measure gas pressure (i.e., “gas pressure gages”) were positioned at multiple locations in the test room to measure the gas pressure in the first 15 vented tests in Phase 1 testing. The pressure sensor in these gages is located in a small annular space behind a surface steel plate with many very small holes, as shown in Figure 1[1]. These gages were developed to protect the pressure sensor from temperature induced drifts while measuring long duration gas pressures in highly confined volumes. However, it was determined after the initial 15 vented tests that the response time of these gages was similar to the duration of the gas pressure histories, which were limited by the very early time failure of the lightweight vent panels. Therefore, only limited useful information was gathered during Phase 1.

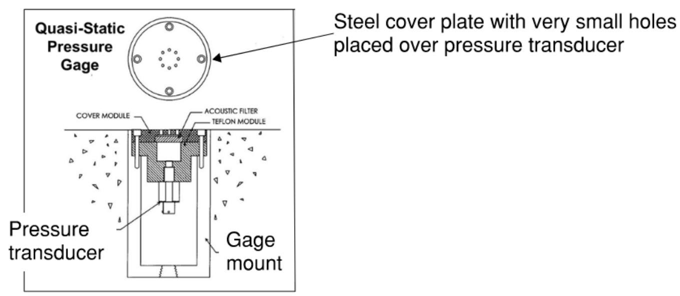


Figure 1. Gas Pressure Gage

After this problem was noted, a new approach was used for the remaining vented tests (i.e., Phase 2 of the testing program) where a corresponding “baseline” test was conducted for each group of the vented tests. The baseline test was otherwise very similar to the group of vented tests (i.e., same volume, charge, charge location, and pressure gages) except that one full side of the test structure was open to the atmosphere to prevent gas pressure buildup inside the test structure. All the other sides of the test structure had rigid construction in the baseline tests. The blast pressure histories measured in the baseline tests were assumed to represent only pressure from the internal shock wave including its reflections (i.e., they were “shock pressure histories”). These shock pressure histories were then subtracted from the blast pressure histories measured in corresponding vented tests to determine a “measured” gas pressure history in each of the vented tests. A total of 43 tests were conducted during Phase 2, which are the primary subject of this paper. These consisted of 11 “groups” of tests, where each group had one baseline test and two to four corresponding vented tests.

This approach used in Phase 2 overestimates the actual gas pressure to a limited extent because the lightweight vent panel in the vented tests causes some limited additional confinement and reflection of the internal shock wave (and thus shock pressure) prior to its failure compared to the uncovered side of the test room in the baseline tests. This limited additional shock pressure is included in the measured gas pressure. However, the additional confinement in the vented tests only represents one additional reflecting surface that fails at early time compared to the five rigid surfaces of the test room in the baseline tests. Therefore, the approach used in these tests was a practical and effective means to measure the relatively short duration gas blast pressure histories with a limited amount of conservatism.

Test Structure

The test structure was built on a heavily reinforced, 3 ft-thick, concrete slab foundation with large 7/8″ diameter bent rebar protruding upward, out of the slab into the center of 7 ft cubic concrete culverts that formed three sides of the test structure. The vertically oriented culverts were filled with concrete around the protruding rebar to form four rigid, monolithic sides of the test room including the concrete floor, as shown in Figure 2. These four surfaces were lined with 0.5 in steel plates with headed studs on their outside surface, protruding through holes drilled in the three abutting concrete culverts that formed sides of the test room. These plates were welded together to form the inner surface of the test structure on four sides. The top (i.e., "roof") of the test structure was a) covered with a large 7 ft cubic concrete block to create confinement at this surface for baseline tests and tests with only a vent wall panel, b) covered with a lightweight roof vent panel, or c) covered with a blast resistant steel plate attached to the structure on three sides that responded elastically to the applied interior blast load.

The two HSS "roof beams" in Figure 2 were used to support a lower roof in tests with a smaller test room volume. The "front wall" of the test structure was a) open in "baseline" tests without gas pressure, b) covered with a lightweight wall vent panel, c) covered with a blast resistant steel plate that responded elastically to the applied interior blast load, or d) covered with multiple large concrete blocks to create full confinement. The test structure could accommodate a lightweight front wall vent panel at the outer edge of the 7 ft cubic volume of the test structure and at a "recessed" position that was recessed inward 1 ft. This also helped to reduce the room volume for some vented tests. All vent panels in the vented tests covered the entire areas of the front wall roof.

Figure 2 also shows four pressure gages placed in the steel plate in the back wall opposite the front wall (see the elevation view in Figure 2 and in the floor plate (see plan view Figure 2) including one pressure gage in the floor directly below the explosive charge. Regular piezoelectric blast pressure gages were used at all of these locations for all Phase 2 tests. For tests with the smaller test room volume, only six of these gages were within the test room volume.

Explosive Charge

The high explosive charge was placed in the same location in all the tests at the center of the 7 ft cubic test structure, as shown in the plan and elevation views in Figure 2**Error! Reference source not found.**. Note this was not the center of a smaller volume that was used in some tests. The charge weights varied from 1.5 to 5 lbs. Three different types of explosive were used in the tests, as shown in Table 1. The heat of afterburning in the table is the difference between the heat of combustion and the heat of detonation for each explosive, where the heat of detonation is released immediately upon detonation and the heat of afterburning is released more slowly as the reactive product gases from the detonation react in the test room with available oxygen. These explosive types were selected to represent explosives with a wide range of afterburning heat relative to heat of detonation. This causes the test data to be more representative for the purpose of developing an improved model to calculate gas pressure in a detonation room.

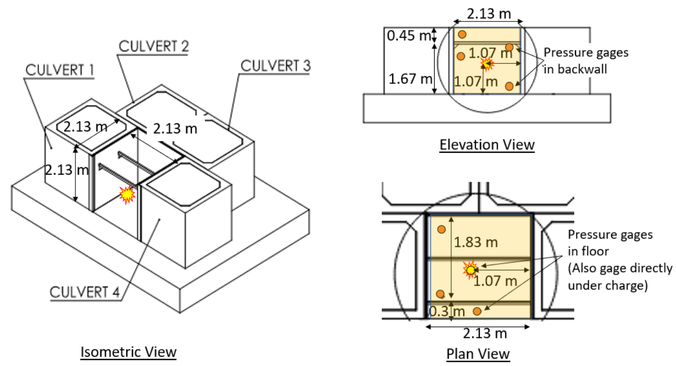


Figure 2. Isometric view of test structure with open roof and front wall

Table 1. Types of High Explosive for Tests

Explosive Type	Heat of Detonation (kJ/kg)	Heat of Combustion (kJ/kg)	Afterburning Heat (kJ/kg)
TNT	4480	14,500	10,020
C-4	5410	10,500	5,090
PETN (93% PETN, 7% wax)	5340	8780	3,440

Test Matrix

Table 2 shows the matrix of vented tests which are divided into groups as shown in the first column. There was a baseline test for each group that had the same charge weight and placement, volume, and pressures gages as the vented tests in the group, as explained previously. The room volume in Table 2 is based on measurements from each test, so it varied somewhat in some cases from the volume corresponding to the nominal test room dimensions. The last four columns of Table 2 show the status of the front wall and roof in each test. One of these two surfaces is always open (i.e., uncovered) in each baseline test and the other surface has a rigid surface or a responding steel plate (RP) that was well attached to the surrounding rigid sides of the test room. The RP functioned as a rigid surface that had a small measured elastic deflection from the applied blast load. These measured deflections were compared to calculated deflections as noted in the table. These comparisons are discussed elsewhere (Oswald,2024).

The vent panels fin Table 2 are described in Table 3. Photographs of tests with many of the test configurations are shown in Figure 3 [2]. Figure 4 shows failure of vent wall panels from high speed video primarily for tests with the lowest loading density including Test 4 from Phase 1 of the testing [2]. The vent wall was fragmented such that is was almost immediately within the fireball in the tests with higher loading densities, as shown in Figure 4 for Test 12 from Phase 1 of the testing.

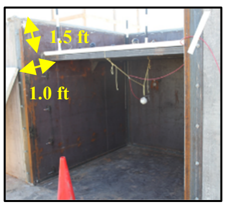
Table 2. Phase 2 Test Matrix

Group	Test	Charge		Nominal Dimensions	Room Volume (ft^3)	Loading Density (lb/ft^3)	No. of Vent Panels	Front Wall		Roof	
		Weight (lb)	Type[1]					Type[1]	Dimensions (ft)[2]	Type[1]	Dimensions (ft)[3]
1	10A	1.2	C4	5.5 x 7 x 6	231	0.0052	0	Open	5.5 ft x7 ft	Rigid	6 ft x7 ft
	5A	1.2	C4	5.5 x 7 x 6	231	0.0052	2	1/4" steel	5.5 ft x7 ft	1/4" steel	6 ft x7 ft
	6A	1.2	C4	5.5 x 7 x 6	231	0.0052	2	26-gauge metal	5.5 ft x7 ft	26-gauge metal	6 ft x7 ft
2	11A	3.6	C4	5.5 x 7 x 6	231	0.0156	0	Open	5.5 ft x7 ft	Rigid	6 ft x7 ft
	13A	3.6	C4	5.5 x 7 x 6	231	0.0156	1	1/4" Lexan	5.5 ft x7 ft	Rigid	6 ft x7 ft
	15A	3.6	C4	5.5 x 7 x 6	231	0.0156	2	1/4" Lexan	5.5 ft x7 ft	1/4" Lexan	6 ft x7 ft
3	16	5	C4	5.5 x 7 x 6	231	0.0216	0	Open	5.5 ft x7 ft	Rigid	6 ft x7 ft
	17	5	C4	5.5 x 7 x 6	231	0.0216	2	1/4" steel	5.5 ft x7 ft	1/4" steel	6 ft x7 ft
	18	5	C4	5.5 x 7 x 6	231	0.0216	2	26-gauge metal	5.5 ft x7 ft	26-gauge metal	6 ft x7 ft
	19	5	C4	5.5 x 7 x 6	231	0.0216	1	26-gauge metal	5.5 ft x7 ft	Rigid	6 ft x7 ft
	20	5	C4	5.5 x 7 x 6	231	0.0216	1	1/4" steel.	5.5 ft x7 ft	Rigid	6 ft x7 ft
4	22	1.2	C4	7 x 7 x 7	340	0.0035	0	RP	7 ft x7 ft	Open	7 ft x7 ft
	8A	1.2	C4	7 x 7 x 7	360	0.0033	2	¼" plywood	7 ft x7 ft	¼" plywood	7 ft x7 ft
	23	1.2	C4	7 x 7 x 7	340	0.0035	1	RP	7 ft x7 ft	26-gauge metal	7 ft x7 ft
	24	1.2	C4	7 x 7 x 7	340	0.0035	1	RP	7 ft x7 ft	¼" Lexan	7 ft x7 ft
5	25	5	C4	7 x 7 x 7	340	0.0147	0	RP	7 ft x7 ft	Open	7 ft x7 ft
	21	5	C4	7 x 7 x 7	352	0.0142	1	26-gauge metal	7 ft x7 ft	Rigid	7 ft x7 ft
	26	5	C4	7 x 7 x 7	340	0.0147	1	RP	7 ft x7 ft	26-gauge metal	7 ft x7 ft
	27	5	C4	7 x 7 x 7	340	0.0147	1	RP	7 ft x7 ft	¼" Lexan panel	7 ft x7 ft
6	33	1.14	TNT	7 x 7 x 7	340	0.0034	0	RP	7 ft x7 ft	Open	7 ft x7 ft
	34	1.14	TNT	7 x 7 x 7	360	0.0032	2	¼" plywood	7 ft x7 ft	¼" plywood	7 ft x7 ft
	35	1.14	TNT	7 x 7 x 7	347	0.0033	1	RP	7 ft x7 ft	¼" plywood	7 ft x7 ft
	36	1.16	TNT	7 x 7 x 7	340	0.0034	1	RP	7 ft x7 ft	1/4" Lexan	7 ft x7 ft
7	37	2.62	TNT	5.5 x 7 x 6	231	0.0113	0	Open	5.5 ft x7 ft	Rigid	6 ft x7 ft
	38	2.6	TNT	5.5 x 7 x 6	241	0.0108	2	¼" plywood	5.5 ft x7 ft	¼" plywood	6 ft x7 ft
	39	2.6	TNT	5.5 x 7 x 6	231	0.0113	2	¼" Lexan	5.5 ft x7 ft	¼" Lexan	6 ft x7 ft
	40	2.6	TNT	5.5 x 7 x 6	236	0.011	1	¼" plywood	5.5 ft x7 ft	Rigid	6 ft x7 ft
	41	2.6	TNT	5.5 x 7 x 6	231	0.0113	1	¼" plywood	5.5 ft x7 ft	Rigid	6 ft x7 ft
8	42	3.44	TNT	7 x 7 x 7	340	0.0101	0	RP	7 ft x7 ft	Open	7 ft x7 ft
	43	3.44	TNT	7 x 7 x 7	347	0.0099	2	26-gauge metal	7 ft x7 ft	26-gauge metal	7 ft x7 ft
	44	3.42	TNT	7 x 7 x 7	340	0.0101	1	RP	7 ft x7 ft	26-gauge metal)	7 ft x7 ft
	45	3.42	TNT	7 x 7 x 7	340	0.0101	1	RP	7 ft x7 ft	¼" Lexan	7 ft x7 ft
9	46	1.2	PETN	7 x 7 x 7	346	0.0035	0	Open	7 ft x7 ft	RP	7 ft x7 ft
	47	1.2	PETN	7 x 7 x 7	360	0.0033	2	¼" plywood	7 ft x7 ft	¼" plywood	7 ft x7 ft
	48	1.2	PETN	7 x 7 x 7	346	0.0035	1	¼" plywood	7 ft x7 ft	RP	7 ft x7 ft
	49	1.2	PETN	7 x 7 x 7	346	0.0035	1	¼" steel	7 ft x7 ft	RP	7 ft x7 ft
10	50	2.74	PETN	7 x 7 x 7	340	0.0081	0	RP	7 ft x7 ft	Open	7 ft x7 ft
	51	2.74	PETN	7 x 7 x 7	347	0.0079	2	26-gauge metal	7 ft x7 ft	26-gauge metal	7 ft x7 ft
	52	2.74	PETN	7 x 7 x 7	340	0.0081	1	RP	7 ft x7 ft	26-gauge metal	7 ft x7 ft
	53	2.74	PETN	7 x 7 x 7	347	0.0079	1	RP	7 ft x7 ft	¼" plywood	7 ft x7 ft
11	54	3.6	PETN	5.5 x 7 x 6	231	0.0156	0	Open	5.5 ft x7 ft	Rigid	6 ft x7 ft
	55	3.6	PETN	5.5 x 7 x 6	231	0.0156	1	26-gauge metal	5.5 ft x7 ft	Rigid	6 ft x7 ft
	56	3.6	PETN	5.5 x 7 x 6	231	0.0156	1	¼" Lexan	5.5 ft x7 ft	Rigid	6 ft x7 ft

Note 1: See Table 3.
Note 2: Vent panel height x width
Note 3: Vent panel length x width

Table 3. Vent Panel Descriptions

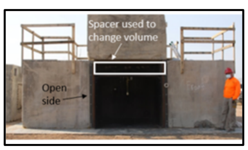
Panel Type[1]	Description	Composition	Areal Weight (lb/ft^2)
Corrugated steel vent panel	26g (0.45 mm) thick panel with 1.25″ high ridges at 12″ spacing	12″ to 16″ wide full height panels screwed together along their height	1.05
Plywood vent panel	0.25″ plywood panels nailed to 1″× 2″ full height studs at 7.3 in spacing	6 pieces of plywood	1.4
Lexan vent panel	0.25″ thick solid panel	Single piece	1.55
Steel vent plate	0.25″ thick solid plate	Single piece	10.2
RP (Responding Plate)[2]	Non-failing steel plate responding elasticly to internal blast load	Steel plate well attached to frame on three side with elastic response to blast load	N/A
Note 1: All vent panels attached to test structure with four (4) Vent-All® fasteners designed to fail in tension at 175 lb force. Note 2: This plate acts as a rigid surface with a small elastic deflection. The measured dynamic deflection of the plate was compared to calculated deflection from dynamic analyses using total measured applied blast pressure and predicted applied blast pressure in the analysis phase of this project.			



a) Setup for Test 6A prior to front wall placement with small volume


b) Setup for Test 21 with corrugated steel vent panel and large volume


c) Setup for fully confined test with large volume



d) Setup for baseline Test 10A with small volume room

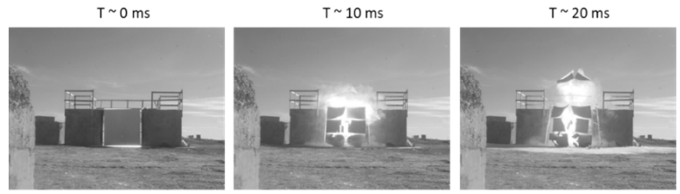

e) Setup for Test 15A with two painted Lexan panels


f) Interior photo of plywood vent panel

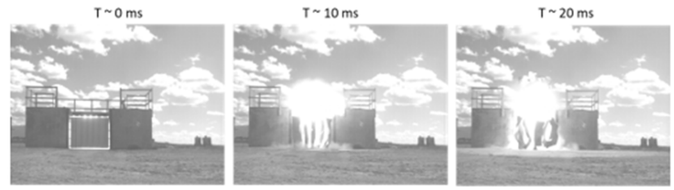
Figure 3. Photographs of test structure for different test configurations

The corrugated steel and plywood vent panels in Table 3 are one-half scale construction (approximately) of lightweight corrugated and plywood panels typically used as vent panels for explosive production bays. The Lexan vent panel was selected as a solid panel with similar areal weight to the corrugated and plywood vent panels that consisted of multiple connected pieces. Ideally, the Lexan panel was a similar lightweight "single piece" panel that would not fracture during venting, but this was only the case for the smallest loading densities. The steel plate vent panel was selected as a heavier vent panel that would not fracture, which was always the case.

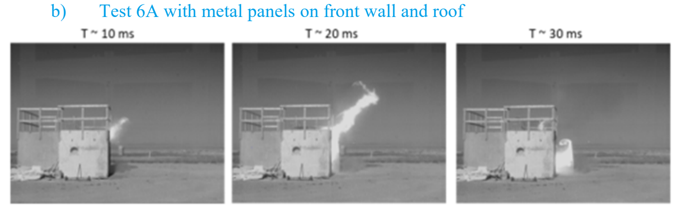
All front wall panels in **Error! Reference source not found.** with a 5.5 ft height (indicating the small test room volume) have a 1.0 ft recessed depth relative to the sides of the concrete culverts making up the sidewalls of the test structure. All roof panels with a 6 ft length (also indicating the small test room volume) have a 1.5 ft recessed depth relative to the top of the three concrete culverts making up the sidewalls and backwall of the test structure. These recessed depths are illustrated in Figure 3a and Figure 5. These vent panels had to move a distance equal to the recessed depth before venting could occur along the sides of vent panels with the recessed depth. The recessed depths represented typical construction at one-half scale for typical DoD explosive operating bays where the walls extend two to three feet beyond the exterior wall and/or roof vent surfaces.



a) Test 8A with plywood panels on front wall and roof



b) Test 6A with metal panels on front wall and roof



c) Test 5A with 0.25 in steel panel on front wall and roof

d) Test 4 with 0.25 in Lexan panel on front wall and roof

e) Test 12 with metal panels on front wall

Figure 4. High speed photographs of tests with low loading densities

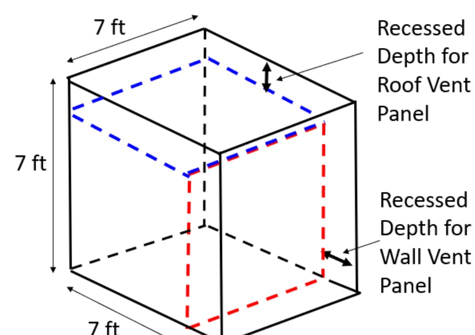


Figure 5. Recessed Depth for Vent Panels

The vented tests and their corresponding baseline test in each group in Table 2 were used to determine the gas pressure history in the vented tests using the multi-step procedure shown below [3]. This procedure is illustrated in Figure 6 in the Appendix for Test 20 in Table 2. The baseline test for Test 20 was Test 16. The averaged pressure gages referred to below included all pressure gages shown in Figure 2 that were within the confined volume for each vented test.

1. Average all the measured pressure histories at all time steps during the baseline test and set all negative pressures in the averaged pressure history to zero. This is Plot 1.
2. Average all the measured pressure histories at all time steps for the similar vented test (i.e., vented test in the same group as the baseline test in Table 2. This is Plot 2.
3. Subtract Plot 1 from Plot 2. This is Plot 3 - the "net subtracted pressure history" for the vented test.
4. Pressure histories in vented and baseline tests are nearly equal during the initial part of Plot 3, implying that the gas pressure is near zero during this time interval, which is the "arrival time" of the gas pressure history during the vented test.
5. Truncate this initial part of Plot 3 equal to the arrival time and shift the remainder of the pressure history to start at time zero. This is Plot 4.
6. Use a 4^{th} order polynomial (typically) to curve-fit Plot 4, where the intercept for the curve fit is set to (0,0). If a 4^{th} order polynomial did not cause a monotonic rise to peak pressure and decrease to ambient pressure, then a 3^{th} order polynomial curve-ft was used.
7. Select the curve-fit that best matches Plot 4. This is Plot 5, which is the final estimated gas pressure history for the vented test. Determine the "rise time" for the gas pressure history equal to the time from zero until the maximum gas pressure in Plot 5.

Table 4 shows the peak pressure, impulse, arrival time, and rise time for the measured gas pressure histories of the baseline and vented tests in Table 2 [3]. Each test group in Table 2 is designated by alternating shaded and unshaded rows in Table 4, where the first test/row in each group is the baseline for the group without gas pressure. The total peak pressure and impulse in Table 4 are the average total measured pressure and impulse from all the internal pressure gages in each test. This includes shock pressure and gas pressure except for the baseline tests that only have shock pressure.

The measured gas pressures in this table are considered conservative since they include some limited shock pressure from the shock wave that is reflected off the vent wall panels prior to their failure that did not occur in the baseline test where the wall was uncovered. The vented tests measured 10% to 15% additional shock pressure compared to the corresponding baseline test based on an analysis with the SHOCK V2 code [3].

Table 4 also shows the measured maximum velocities of the vent panels from each vented test and the gas pressure arrival time and gas pressure rise time. The gas pressure arrival time and gas pressure rise time are illustrated in Figure 4 in the Appendix. These two times are only shown for the vented tests with one vent panel and with two steel plate vent panels.

The gas pressure histories from tests with two lightweight vent panels covering surfaces of the test structure were much more difficult to distinguish from the shock pressures than they were for the other vented tests due primarily to the much faster venting and much lower magnitude of gas pressures during these tests. The arrival times and rise times were therefore not considered very reliable for these tests.

A similar smaller series of fully confined tests was conducted with only minimal vent area using the test set up shown in Figure 3c. These tests included a baseline test and one corresponding confined test. The gas pressure history was determned for each confined test using the same approach described for the vented tests with the exception that a 5^{th} order polynominal curve fit was used for Step 6. Figure 7 in the Appendix shows measured average pressure histories for the confined Test 60 and the corresponding baseline test and the curve-fit to the net measured gas pressure history that represents the measured gas pressure history for this test. The purpose of these confined tests was primarily to measure the rise rise time to peak gas pressure in fully confined tests (i.e., tests without any significant venting). Considerably more detailed information from all the testing is available elsewhere [2],[3].

Table *5* shows the peak measured gas pressure and impulse from the fully confined tests. The large concrete block that provided confinement on the side of the test struture that was open during baselnie tests did not provide a perfect seal and it moved a small amount durnig the confined tests. The area of the open crack around the perimeter of this block was measured before and after each confined test and the average of these two areeas is shown in Table *5* as the open vent area for each test. Some later time gas pressure was probably caused by burnnig of a small styrofoam test stand in Tests 66 amd 67.

References

1. Sheffield, Craig, Private communications via email, 2019.
2. Sheffield, Craig S. and Sellers, Cameron," Internal Blast Test Series Final Test Report," DTRA FTR-21-64, Prepared by Applied Research Associates, Inc. for Defense Threat Reduction Agency (DTRA) Research and Development Directorate Enabling Capabilities Department, September, 2021.
3. Oswald, Charles, "Final Development of an Improved Method to Calculate Gas Pressure from Internal Detonations," Prepared by AG&E for APT Research, Inc., September 30, 2024.

Contact Information

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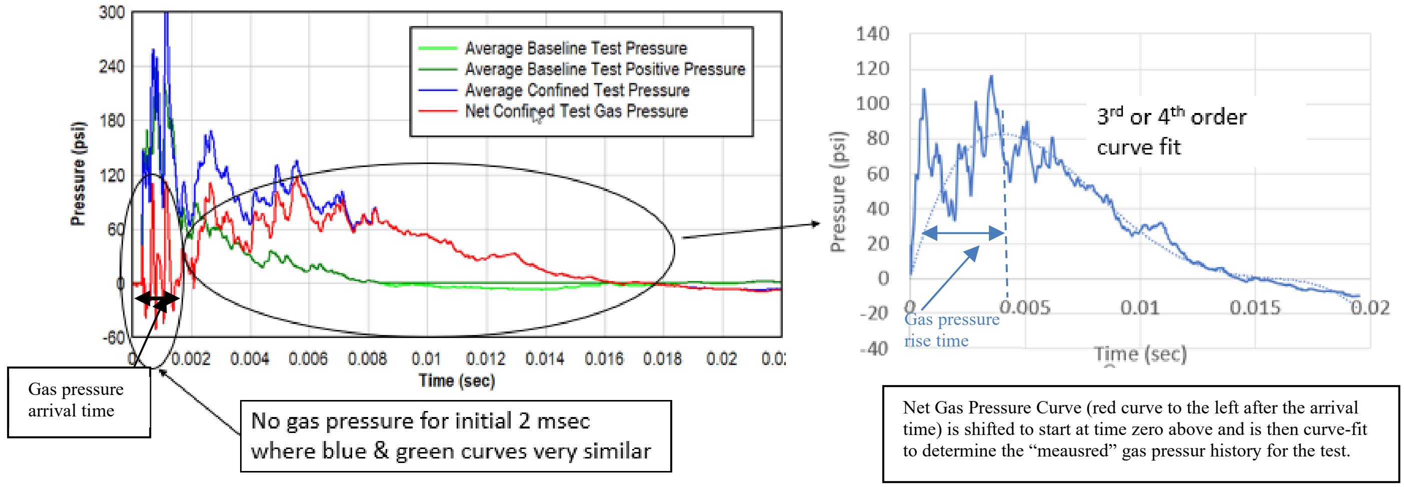
Appendix

Baseline Test: Test 16, Vented Test: Test 20



1. Average time history of gages in baseline test
2. Same as No. 1 except negative phase set to zero
3. Average time history of gages in initially confined test
4. Net pressure history (approx. gas pressure history) = Avg confined – Avg baseline with negative phase set to zero

Figure 6. Example of measured gas pressure history from confined vented test in Test 20

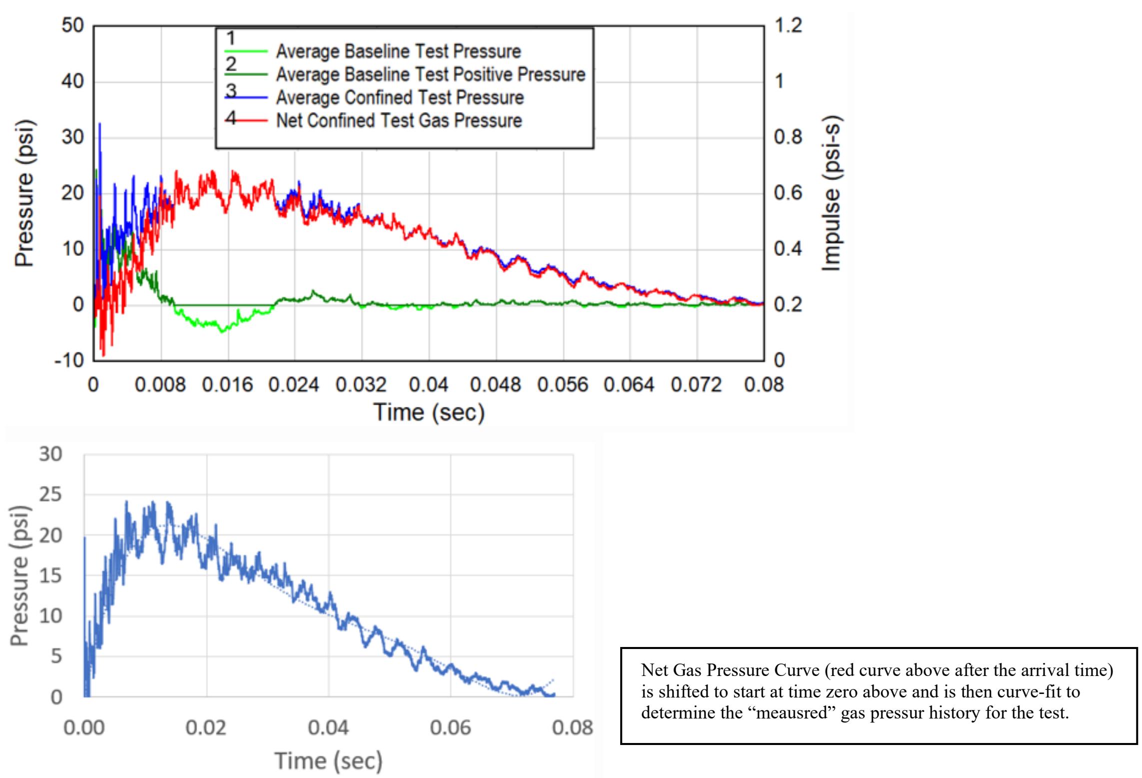


Figure 7. Example of measured gas pressure history from fully confined test in Test 60

Table 4. Results from Vented Tests

Test	Load Density (lb/ft^3)	Room Volume (ft3)	Vent Panel Area (ft2)	Measured Total Blast Pressure: Peak Pressure (psi)	Measured Total Blast Pressure: Impulse (psi-ms)	Measured Gas Pressure: Peak Pressure (psi)	Measured Gas Pressure: Impulse (psi-ms)	Measured Gas Pressure: Arrival Time (ms)	Measured Gas Pressure: Rise Time (ms)	Maximum Velocity (ft/s): Wall Panel	Maximum Velocity (ft/s): Roof Panel
10A	0.0052	231	0	173	149						
5A	0.0052	231	80.5	156	408	27	245	2.8	4.5	144	147
6A	0.0052	231	80.5	174	165	6	12			422	380
11A	0.0156	231	0	429	309						
13A	0.0156	231	38.5	421	496	26.5	142	2.4	2.1	775	
15A	0.0156	231	80.5	449	339	27	34			697	732
16	0.0216	231	80.5	526	407						
17	0.0216	231	80.5	570	870	60	395	2.1	3.3	330	331
18	0.0216	231	38.5	592	371	23	24			831	969
19	0.0216	231	38.5	518	535	18	95	2.3	1.9	1300	
20	0.0216	343	49	590	1114	81	630	2.2	4.0	390	
21	0.0142	231	80.5	557	494	20	103	2.8	2.0	993	
22	0.0035	343	0	152	127						
8A	0.0033	343	98	178	147	5	15			385	375
23	0.0035	343	49	134	202	11.2	60	3.4	2.1		437
24	0.0035	343	49	135	212	13	71	3.5	2.4		458
25	0.0147	343	0	513	358						
26	0.0147	343	49	561	485	20	98	2.4	1.9		1163
27	0.0147	343	49	731	532	18	85	2.3	2		1191
33	0.0034	343	0	174	145						
34	0.0032	346.9	98.56	128	124	5	22			338	317
35	0.0033	346.9	49	90	175	11.6	59	3.6	1.6		362
36	0.0034	341	49	72	186	13.7	75	3.6	2.7		242
37	0.0113	231	0	238	261						
38	0.0108	236	81.34	253	252	11	12			563	597
39	0.0113	236	81.34	258	272	13	19			443	553
40	0.011	236	39.34	189	349	18	115	2.5	2.8	661	
41	0.0113	231	38.5	275	392	20	111	2.5	2	572	
42	0.0101	338.1	0	314	244						
43	0.0099	338.1	97.3	309	271	15	28			511	646
44	0.0101	338.1	49	320	357	17	94	2.8	1.7		473
45	0.0101	340.1	49	280	338	21	123	2.6	1.9		810
46	0.0035	350.8	0	238	184						
47	0.0033	350.8	99.12	230	146	5	19			422	394
48	0.0035	350.8	50.12	339	244	10.9	54	3.5	3.8	370	
49	0.0035	345	49.28	236	395	22	226	3.3	4.0	152	
50	0.0081	338.1	0	197	175						
51	0.0079	338.1	97.3	471	291	13.4	28			430	438
52	0.0081	338.1	49	262	321	17	85	2.5	2.2		539
53	0.0079	346.9	49	387	338	22	83	2.9	1.6		866
54	0.0156	231	0	376	299						
55	0.0156	231	38.5	842	449	16	80	2.3	2.1	547	
56	0.0156	231	38.5	504	487	23.7	130	2	2.5	570	

Table 5. Results from Fully Confined Tests

Test	Charge: Weight (lb)	Charge: Type[1]	Room Volume (ft^3)	Loading Density (lb/ft^3)	Uncovered Vent Area (ft^2)	Measured Gas Pressure: Pieak Pressure (psi)	Measured Gas Pressure: Impulse (psi-ms)	Measured Gas Pressure: Arrival Time (ms)	Measured Gas Pressure: Rise Time (ms)
60	0.25	PETN	160	0.0016	1.48	21.0	788	3.0	13
61	0.5	PETN	159	0.0031	1.41	38.0	1430	2.5	12
62	0.5	PETN	358	0.0014	1.46	12.7	479	3.0	12
66	0.25	TNT	161	0.0016	1.78	17.7	540	3.2	12
67	0.5	TNT	161	0.0031	1.95	30.4	806	2.8	11
68	0.5	TNT	360	0.0014	1.90	15.1	605	3.8	12