PROPELLANT LOADS TESTING:
APPLICATION TO FACILITY DESIGN

by

Michael A. Polcyn
Wilfred Baker Engineering, Inc.
San Antonio, Texas

Scott A. Mullin
Southwest Research Institute
San Antonio, Texas

ABSTRACT

Today, most new automobiles produced in the United States are required to have airbags installed to protect passengers in the event of a collision. Airbag systems are designed to deploy a gas-filled bag upon vehicle impact. When the system is triggered, a gas producing propellant is initiated. The gases rapidly fill and open the airbag, thus providing a cushion for passengers. In an airbag system, the propellant combustion is a controlled explosion. However, several operations in propellant processing for use in airbag cartridges can be hazardous. Operations such as pressing, granulating, slugging, etc., can impart impulsive or thermal energy which can initiate the propellant. Hazards from these operations are a concern due to the quantity of propellant typically required for the operations to be efficient.

To support design of propellant operating bays and the design of modifications to existing operating bays, one airbag manufacturer had tests performed to characterize their propellants. One of their principal propellants has a hazard classification of 1.3. Most of the characterization tests were not adequate to predict blast loads for a complete range of design variables. Therefore, loads tests were performed to simulate a typical operating bay. Pressures were measured both inside the bay of occurrence and at several adjacent points. This paper presents a summary of the test program and an overview on use of the test data for design purposes.

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1. Background

A typical internal load from a high explosive consists of a “shock” loading phase and a “gas,” or “quasi-static,” loading phase. The shock load is produced by a shock wave which propagates from the explosion source and reflects off interior surfaces of the room. As the wave reflects or passes across surfaces, a pressure pulse is imparted to the surface. The shock load is characterized by an instantly rising pressure pulse which decays rapidly (over a few milliseconds). For analysis and design purposes, a shock load is typically characterized by a triangular pulse which instantly rises to its maximum pressure and decays linearly. The area under the shock load time history is known as the shock impulse. Generally, the magnitude of the shock load is a function of the explosive weight, the type of explosive, the distance from the explosive to the point where the load is measured, and the orientation of surfaces in the room which can cause reflecting surfaces or obstructions to the shock wave.

The gas, or quasi-static, load is produced by the gases generated from the explosion. Typically, this pressure is much less than the shock pressure, and the duration of the load is much longer. Over a short period of time, the pressure rises to a maximum, which is a function of the explosive weight and the room volume. The pressure decays over a period of time dependant on the explosive weight, the room volume, the vent area, and characteristics of the vent panel.

One of the propellants used by a major airbag manufacturer is classified as a hazard classification 1.3 explosive. A 1.3 explosive, by definition, deflagrates, and does not detonate. However, experiences by this manufacturer have indicated that shock waves may be produced by some explosions of their propellant, possibly from a detonation or fast deflagration. In order to evaluate this effect, tests were performed simulating operating conditions. Test parameters included propellant weight, propellant form (tablet and granular), room size, and frangible panel geometry. Also, a typical building configuration was modeled to evaluate effects on adjacent areas.

In this paper, data were plotted using “scaled” terms such that data from several tests could be gathered into a fewer number of relationships. The loading density, W/V, is the ratio of the propellant weight, W, to the room volume, V. The shock impulse, i_s, and gas impulse, i_g, are scaled by $W^{1/3}$ to give scaled impulse values. Distances, R, are also scaled by $W^{1/3}$ to give scaled distances or standoffs. The vent area can be a significant factor in determining the gas impulse. Vent areas, A, are scaled by $V^{2/3}$ to give the scaled vent area. Also, the maximum gas pressure rise rate, $(dP/dt)_{max}$, is scaled by $W^{1/3}$ to give a scaled pressure rise rate. These values are discussed in the following paragraphs and used in the associated plots.

2. Test Setup

The tests that were performed for this program were conducted at subscale dimensions from typical operating bays. The average linear geometric scale factor, denoted by λ, is computed from the cube root of the volume ratio between the test chambers and actual operating bay size. A survey of the client’s facilities indicated that the volume of processing bays vary from 810 ft^3 to 10889 ft^3. Using one of the remote operating bays (4539 ft^3 volume) as typical, the scale factor for the test chamber (volume of 187.5 ft^3) is computed as:

$$\lambda = (187.5 / 4539)^{1/3} = 1/2.89.$$

Most of tests were conducted in a test chamber (see **Figure 2.1** and **Figure 2.2**) which has an internal width of 60 inches, height of 60 inches, and a depth of 90 inches. The roof, floor, and walls adjacent to the front opening are steel clad concrete, as shown in **Figure 2.1**. Vent panels, described subsequently, covered the front opening of the chamber. For tests with a reduced vent area, a 2 inch-thick steel plate reduced the size of the front opening. The wall directly opposite the front was made of 2 inch-thick steel plate. The test chamber was sealed so that the only exit for blast pressures was through the vent panel. Note that tests were also conducted in a smaller chamber, which is not discussed in this paper.

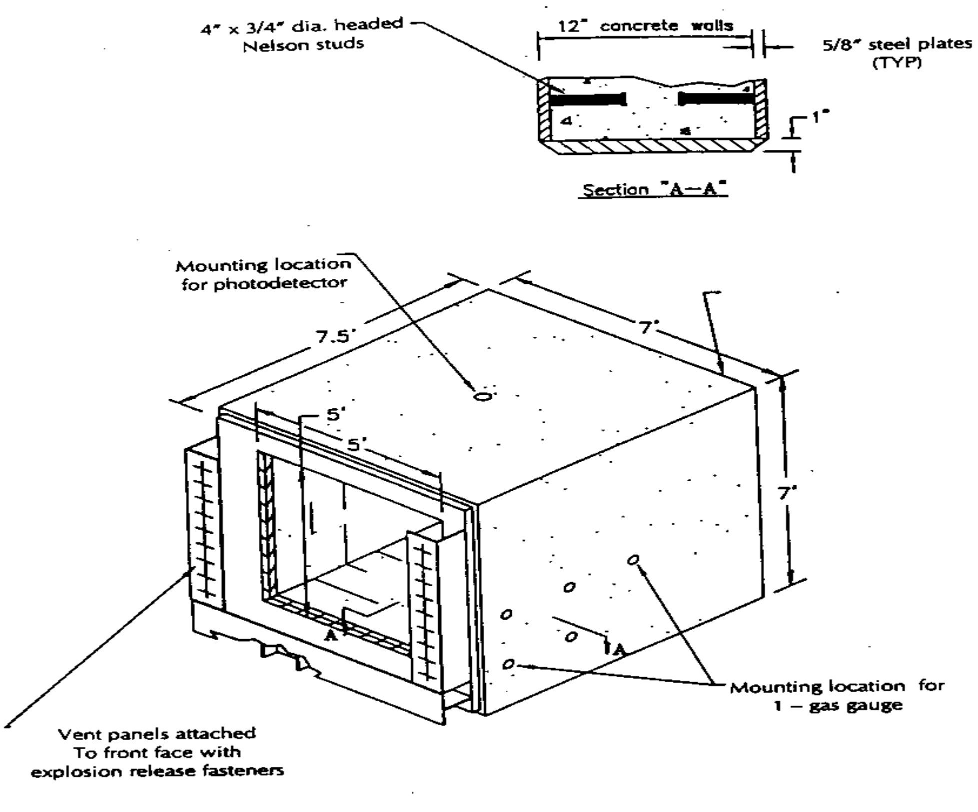


Figure 2.1 Schematic of Large Blast Chamber Test Fixture

Figure 2.2 Photo of Large Blast Chamber Showing Attached Vent Panel

The vent panels used as representative for this study (from typical remote operating bays) are 17 ft x 12 ft in area, with an areal density of 5 lb/ft^2. These values provide a total weight of 1020 lbs. To provide subscale response that was representative of full scale, it was desired to design the subscale vent panel such that its release velocity was the same as it would be in full scale. The propellant explosion loads the vent panel with a rapid pressure–time pulse which is best characterized by its integral, the impulse. From the impulse-momentum relationship:

$$I = M\ V;$$

where I is total impulse (lb - s); M is mass (slugs); and V is velocity (ft/s).

Blast scaling theory states that total impulse in a subscale model is related to total impulse in full scale by I (model) = $\lambda^3 \cdot$ I (full scale). To keep the vent panel velocity the same in the subscale blast chambers, therefore requires the panel mass to also scale by λ^3. This means that the vent panels in the large test chamber have to weigh 1020 lb / $(2.89)^3$ = 42.2 lb.

The vent panels are blown outwards when explosion release fasteners give way. The typical design release pressure used in the client's facility is 30 lb/ft^2, or 0.208 psi. This release load was replicated in the subscale experiments described herein by multiplying the release pressure by the reduced area. For example, the large blast chamber shown in **Figure 2.1** and **Figure 2.2** has a nominal vent area of 5 ft x 5 ft = 25 ft^2 . Multiplying this value by the 30 lb/ft^2 pressure release value requires a total explosion release fastener load of 750 lb. Explosion release fasteners used for the tests had specific force ratings of 70 or 175 lb. For the requirements of the 750 lb release load, four of the 175 lb fasteners were used, which totals 700 lb resistance, close to the desired 750 lb. Fastener requirements for reduced vent sizes were calculated similarly.

To simulate a layout with parallel processing bays and barriers in front of the frangible walls, concrete cubicles were arranged near the blast chambers. **Figure 2.3** shows a schematic of the layout. **Figure 2.4** and **Figure 2.5** are photos of the test setup. The concrete cubicles opposite the test structure were seven or more feet high, and provided reflecting surfaces. The two cubicles which contain pressure gauges have their faces parallel to the vent panel opening of the blast chamber. They simulate parallel processing bays, and the pressure measurements taken there were intended to characterize the load which occurs on adjacent vent panels during an explosion.

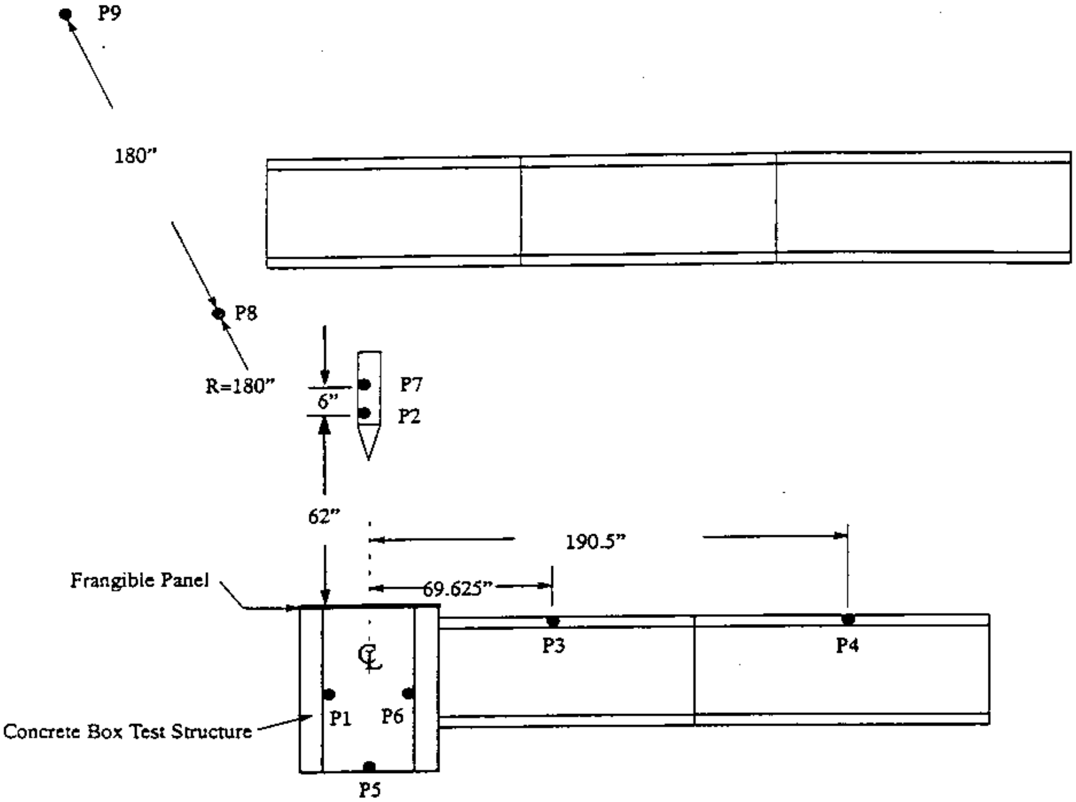


Figure 2.3 Layout of Blast Chambers, Reflecting Walls, and Pressure Gauges

Figure 2.4 Photo of Large Test Chamber and Concrete Reflecting Walls Parallel to Front Opening

Figure 2.5 Photo Showing Concrete Reflecting Walls Opposite Blast Chamber

The pressure gauges located inside the blast chamber recorded the pressure wave as the propellant exploded. Additional gauges were located in a heavy steel wedge block (seen in **Figure 2.4**) placed directly in front of the vent panel. Far field measurements at pencil gauges provide indications of the drop in pressure magnitude with distance in an area away from the reflecting surfaces.

Table 2.1 Inflation Systems 3110 Propellant Testing Systems

Test Number	Date	Propellant Type	Propellant Placement	Initiation Location	Propellant Weight (lb)	Chamber Size (L,W,H) (inches)	Vent Panel Size (W,H,T) (inches)	Vent Panel Weight (lb)	Notes
1	2/18/98	granulated	center	top	5.0	90x60x60	65x65x1/2	42.1	
2	2/18/98	granulated	center	top	5.0	90x60x60	65x65x1/2	42.1	2 inch void above propellant
3	2/18/98	none	N/A	N/A	N/A	90x60x60	65x65x1/2	42.1	gauge test with 40g of C-4 explosive
4	2/18/98	granulated	center	top	10.0	90x60x60	65x65x1/2	42.1	
5	2/20/98	granulated	center	bottom	10.0	90x60x60	65x65x1/2	42.1	first bottom initiated
6	2/20/98	granulated	center	bottom	20.0	90x60x60	65x65x1/2	42.1	
7	2/20/98	granulated	center	bottom	5.0	90x60x60	65x65x1/2	42.1	
8	2/21/98	granulated	center	bottom	10.0	90x60x60	65x65x1/2	42.1	large reaction
9	2/23/98	granulated	center	bottom	20.0	90x60x60	65x65x1/2	42.1	
10	2/23/98	granulated	center	bottom	5.0	90x60x60	65x65x1/2	42.1	low energy test
11	2/24/98	tablets	center	bottom	5.0	90x60x60	65x65x1/2	42.1	
12	2/24/98	tablets	floor	bottom	10.0	90x60x60	65x65x1/2	42.1	tablets placed on floor
13	2/24/98	tablets	floor	bottom	20.0	90x60x60	65x65x1/2	42.1	
14	2/24/98	granulated	floor	bottom	40.0	90x60x60	65x65x1/2	42.1	largest test
15	2/25/98	granulated	floor	bottom	10.0	90x60x60	46.4x46.4x1/2	21.0	
16	2/25/98	tablets	floor	bottom	10.0	90x60x60	46.4x46.4x1/2	21.0	
17	2/25/98	granulated	floor	bottom	20.0	90x60x60	46.4x46.4x1/2	21.1	large reaction
18	2/26/98	granulated	floor	bottom	2.5	45x30x30	32x32x1/4?	5.3	

Notes:
1) For tests with the 65”x65”x1/2” vent panel, 4 of the 175-lb explosion release fasteners were used, one centered on each side.
2) For tests with the 46.4”x46.4”x1/2” vent panel, 6 of the 70-lb explosion release fasteners were used, 2 on the top and bottom, 1 each on the sides.
3) The vent panel on the ½ scale chamber, Test 18, used 4 x 70-lb explosion fasteners, one on each side.

The test matrix is shown in **Table 2.1**. For all tests, the propellant was contained within cardboard tubes, with plastic insert end caps. **Figure 2.6** shows one of the tubes with 5 lb of propellant. This particular tube was 5 inches in diameter and 7 inches long. For Tests 1 through 11, the propellant tube was suspended at mid-height in the blast chamber. For Tests 12 through 18, the propellant tube was placed upon a plywood sheet on the floor of the chamber (see **Figure 2.7**).

Figure 2.6 Propellant Tube with 5 lbs of Propellant Suspended at Chamber Center

Figure 2.7 Propellant Tube Placed on Floor

The propellant was supplied in both tablet and granulated form. The initiator used to start the explosion for all tests was an SQ-80 exploding bridge wire squib, supplied by Reynolds Industries. For the first three tests the initiator was placed at the top center of the propellant, 1 inch deep, pointing downwards. Using this arrangement, the propellant tended to explode in two distinct reactions which involved a low energy-level burn followed, 3 to 4 seconds later, by a larger explosion. This type of reaction was judged to be not realistic; therefore, for all subsequent tests, the squib was placed at the bottom of the propellant. This resulted in a single explosive reaction when the squib was initiated.

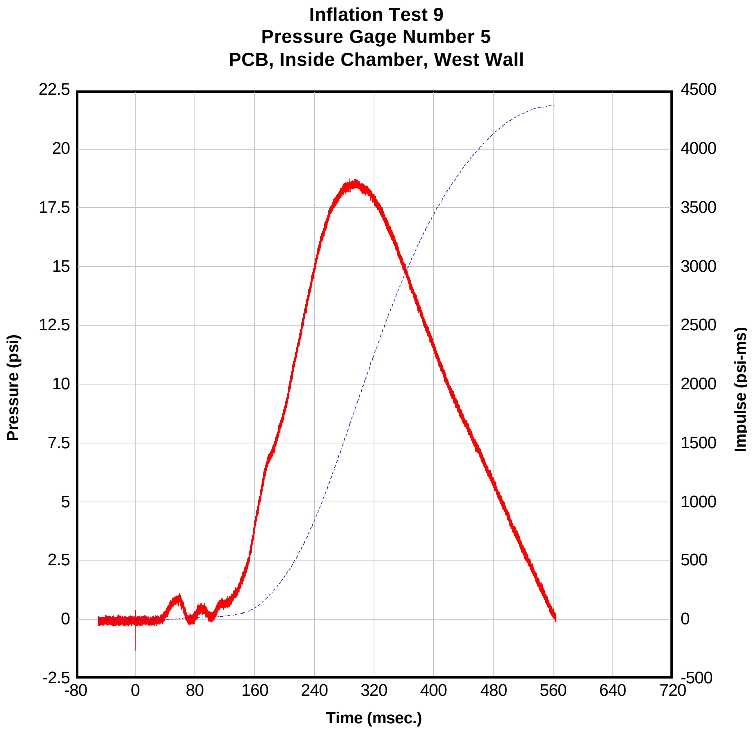
3. Observations for Internal Loads Data

A typical internal pressure history is shown in **Figure 3.1**. **Figure 3.2** is a plot of the maximum internal gas pressure as a function of the loading density. Several items are worth noting.

1. For the granular and tablet tests with the full vent opening ($A/V^{2/3} = 0.763$), the pressure increases as the charge weight increases.
2. The above trend is also demonstrated for the reduced vent area tests ($A/V^{2/3} = 0.382$), but it is not clear why the pressures were lower for two of the tests with smaller loading densities. Test No. 17, on the other hand, produced significantly higher pressures than the corresponding test with an entire wall as a vent wall. This was the expected effect of the reduced vent area.
3. From the full vent area tests, it appears that the tablets produce higher pressures than the granular propellant.

Figure 3.3 shows the scaled maximum pressure rise rate as a function of the loading density. Except for Test No. 17 (granular test with a reduced vent area), the pressure rise rate is roughly between 0.05 and 0.30 psi/ms, with the scaled pressure rise rate increasing with loading density. The data for tablets and granular seem to fall together. Some of the tests with the reduced vent area had a slower pressure rise rate to peak pressure than tests with the full vent area. This was not expected, but at this time, we have no explanation for this behavior.

Figure 3.4 shows the scaled impulse as a function of the loading density. Test data is given for two scaled vent areas. For the tests with full venting, the scaled impulse is smaller for increasing scaled propellant weight. Also, the scaled impulse for tablets is greater than that for granular material. However, as observed in peak pressure measurements, the effect of scaled vent area is not apparent.



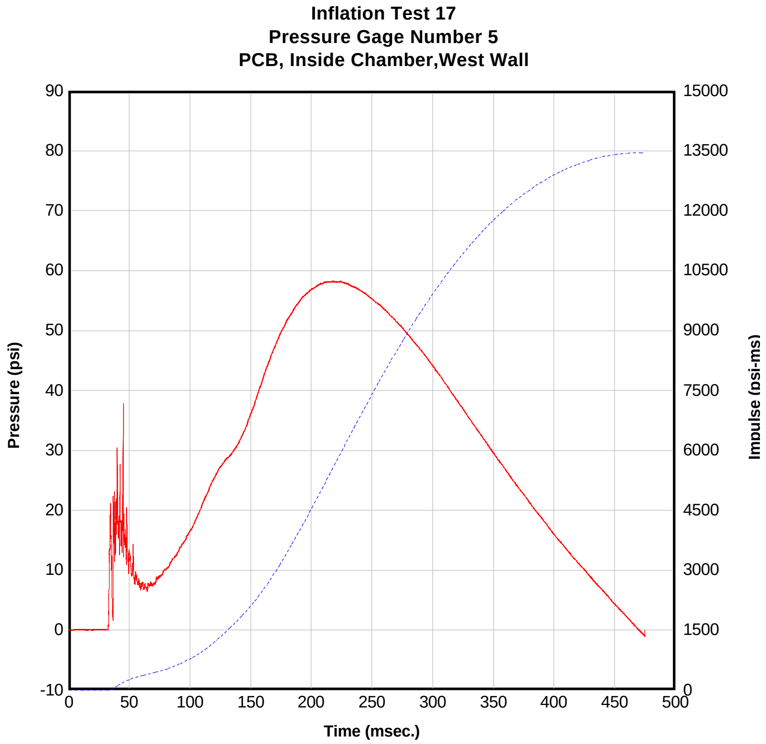


Figure 3.1 Typical Internal Blast Load History

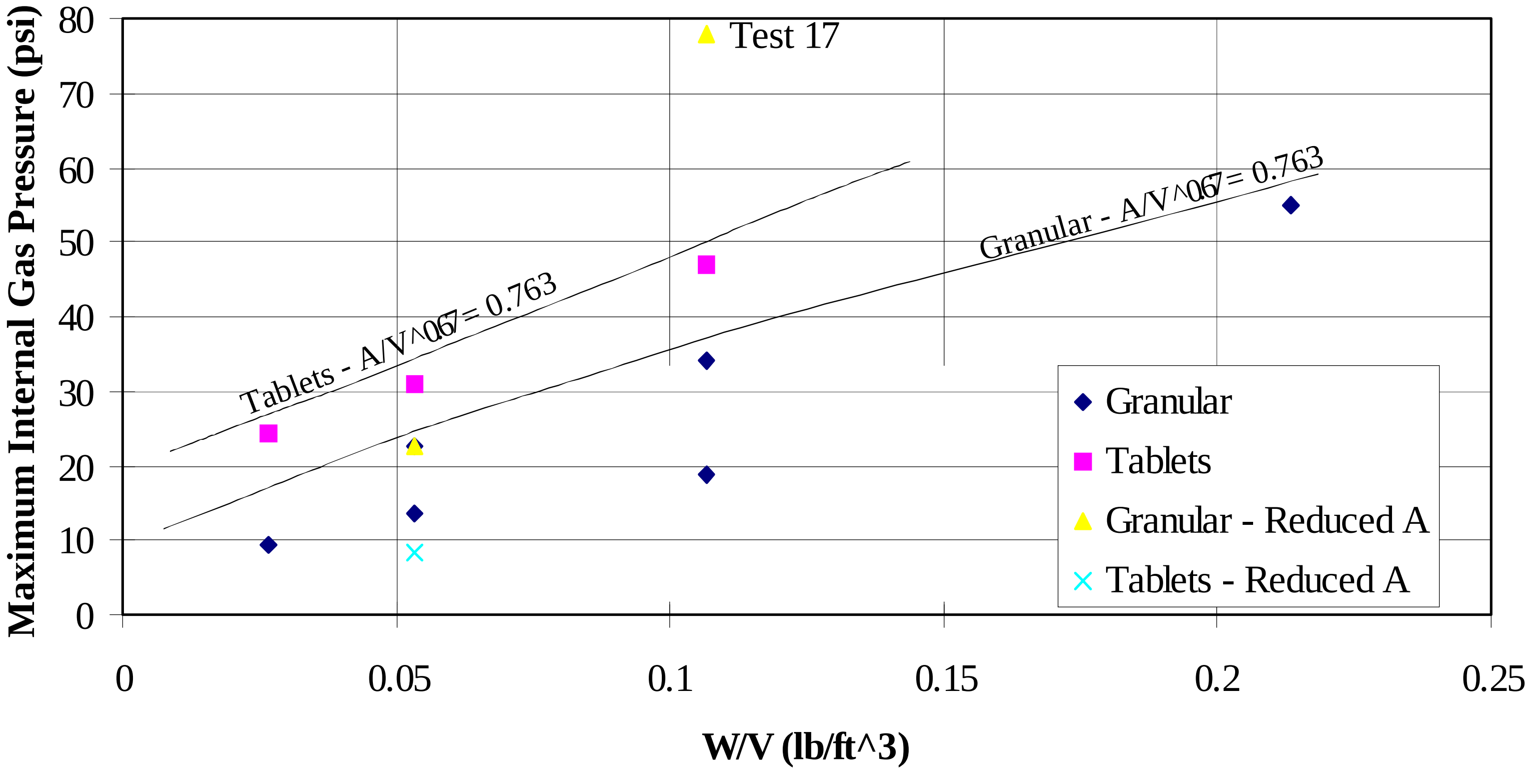


Figure 3.2 Maximum Internal Gas Pressure

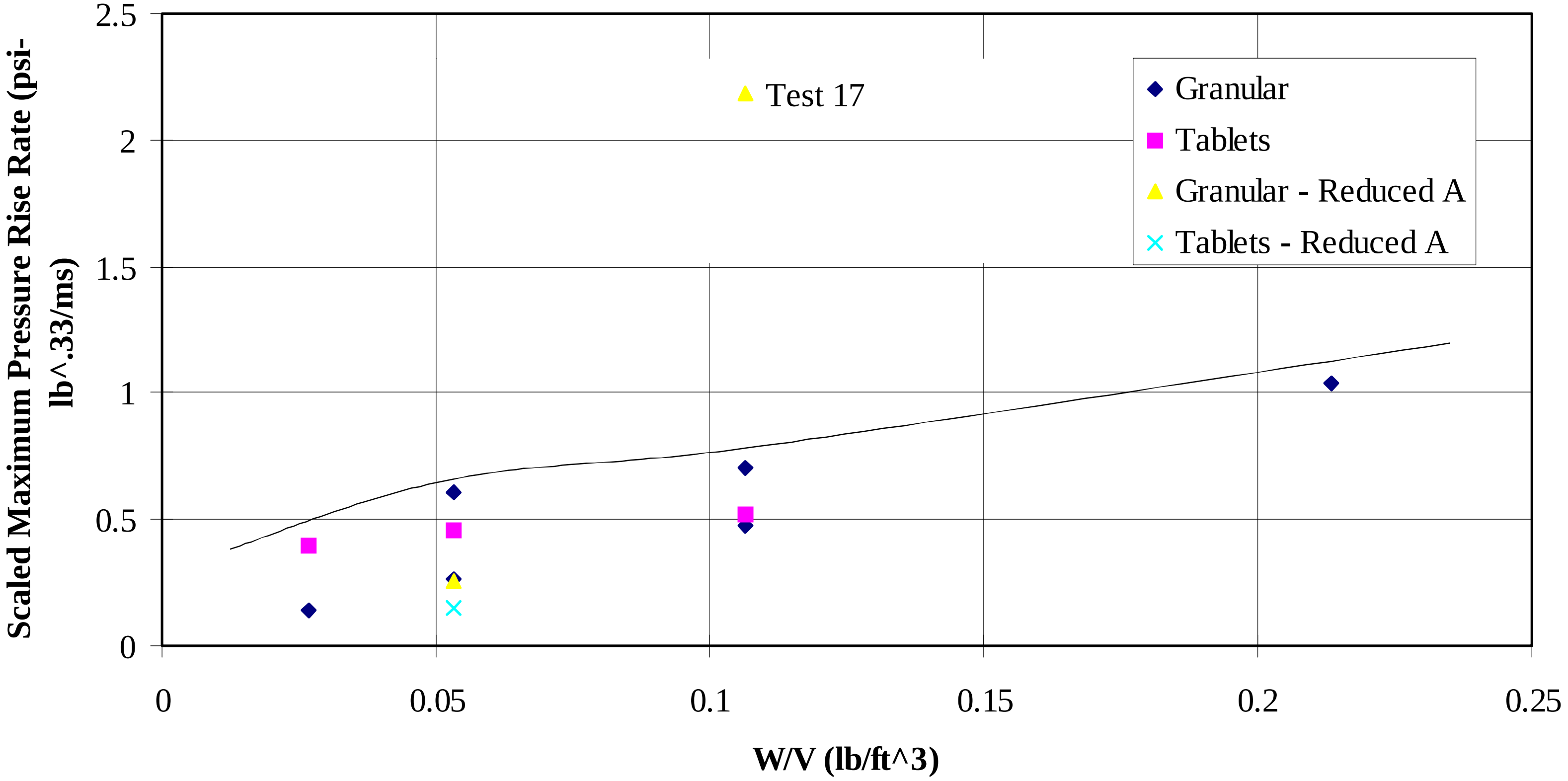


Figure 3.3 Scaled Gas Pressure Rise Rate

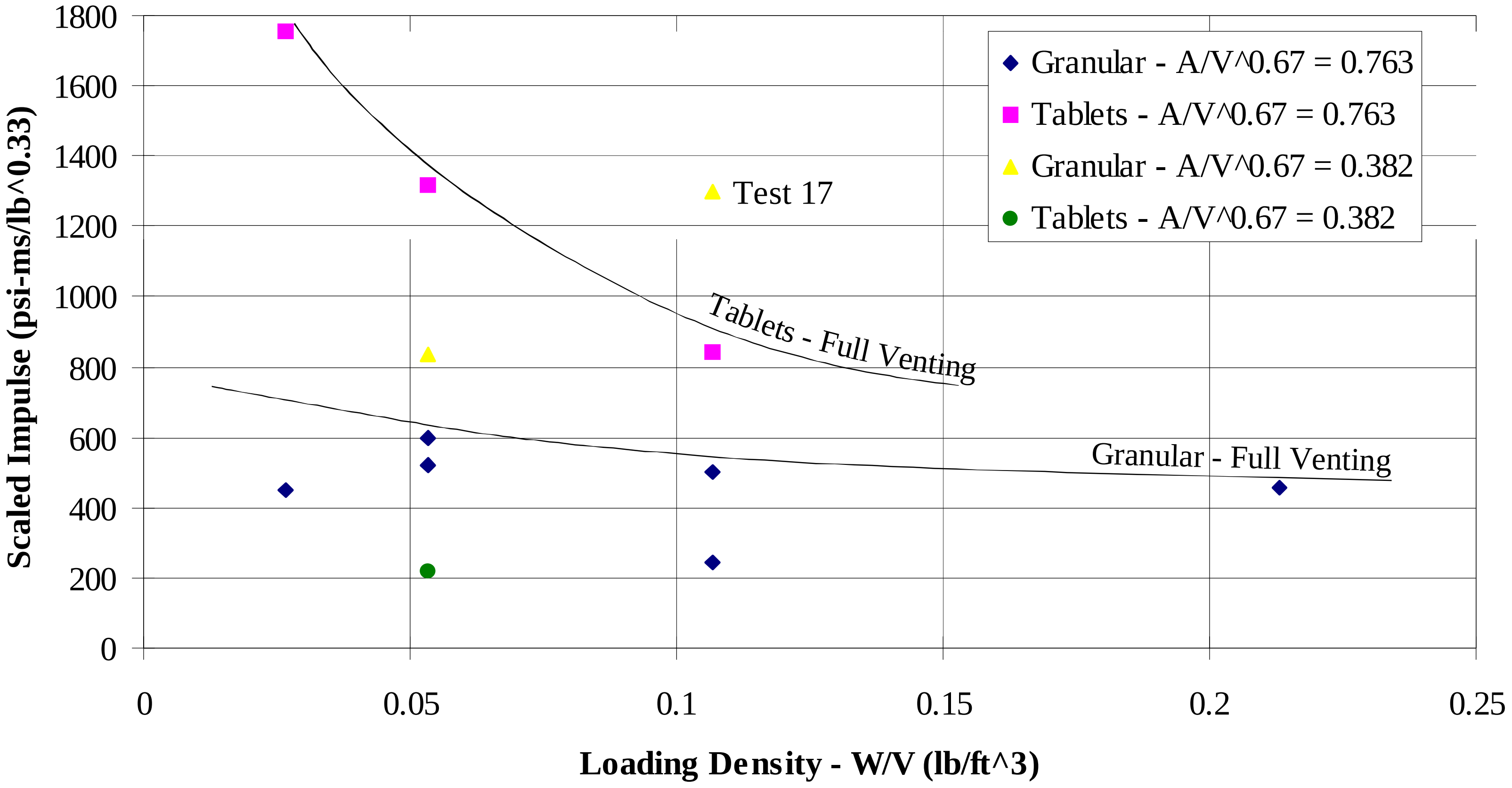


Figure 3.4 Scaled Gas Impulse

Several other points were noted in the data review:

- Using TNT curves for quasi-static gas pressures and comparing to the peak gas pressures in the tests, the TNT equivalency ranged from about 0.011 to 0.077.
- A small "shock" loading phase was observed in several tests. Figure 3.1 shows pressure traces with no shock load phase and with a shock load phase. However, a trend was not identified defining when shocks are produced and when they aren't. The measured shock load was compared to shock pressures and impulses calculated with the computer code SHOCK[1] for high explosives. For tests where shocks were present, the TNT equivalency based on shock pressures was less than 1% in all cases, and the TNT equivalency based on shock impulse was about 1 to 2% for all cases except two tests discussed below. There seemed to be a higher occurrence of shocks when the propellant was placed on the floor and with the reduced vent area. This indicates that a full vent opening should be used whenever possible and, if possible, the propellant containers should be raised off of the floor, particularly in high hazard areas.

  Two tests produced significantly higher shock impulses. In test 8, with 10 lb of granular material, the sample was hung from the ceiling and the explosion was vented through the full vent area. The TNT equivalency, based on shock impulse, was about 10%. Test 17 had 20 lb of granular material, but the specimen was on the floor and the reduced vent area was used. The shock impulse from this test was about 0.38 psi-sec, which corresponds to a TNT equivalency of about 25%.
- Shock and gas loads (peak pressure and impulse) tended to be slightly higher in tests where the propellant was placed on the floor rather than hung from the ceiling and centered in the test structure. Note also that the tests where the propellant was on the floor were the tests performed with tablets and a full vent opening, tests with tablets and granular material and a reduced vent opening, the test in the half-size box, and the test with 40 lb of granular material with a full vent opening. These factors may also have played a role in contributing to the higher loads.

4. Observations for External Loads Data

External positive phase loads from all of the tests are summarized in **Figure 4.1** and **Figure 4.2**, which show the maximum pressure and the maximum scaled impulse, respectively, measured at the culverts. The pressure and impulse are plotted as a function of the scaled standoff from the center of the front wall of the test structure. The upper limit of most of the data can be bounded by Curve A on both figures. Tests 8 and 17 produced significantly higher loads outside the test structure than the other tests; this trend is consistent with the observations made on the internal test data. Curve B was plotted on Figures 8 and 9 to show the upper bounds measured during the tests.

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[1] Wager, P. and Connett, J., "SHOCK User's Manual," Version 1.0, Naval Civil Engineering Laboratory, Port Hueneme, CA, January 1988

The external gauges also indicated that a negative pressure was encountered on the culvert surfaces adjacent to the test structure. The maximum negative pressures are plotted in **Figure 4.3** as a function of the scaled standoff. As shown, the suction pressure for most tests is relatively low with a magnitude less than about 0.6 psi. The suction pressure is much greater for Test Nos. 8, 17, and 18.

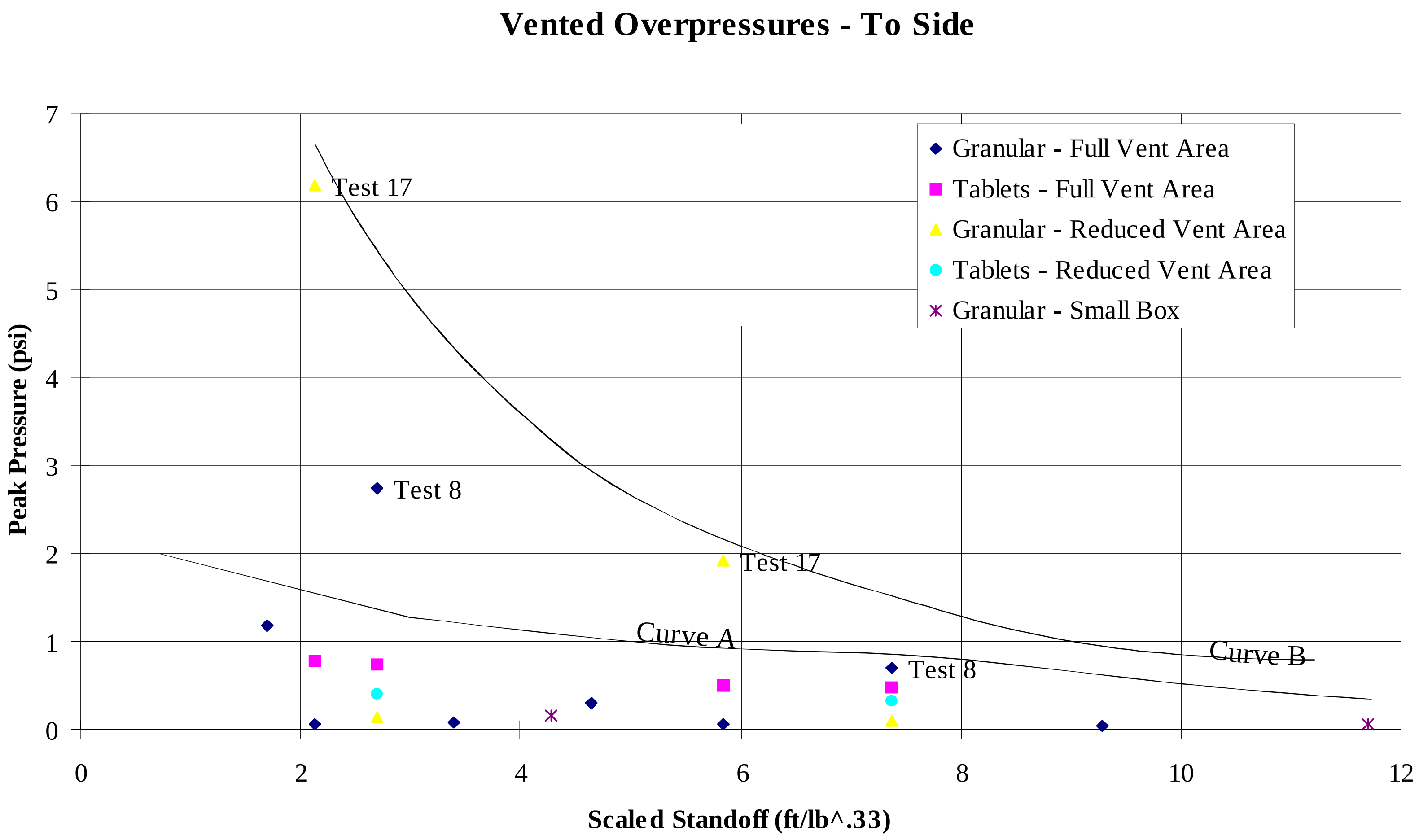

Figure 4.1 Vented Shock Overpressure

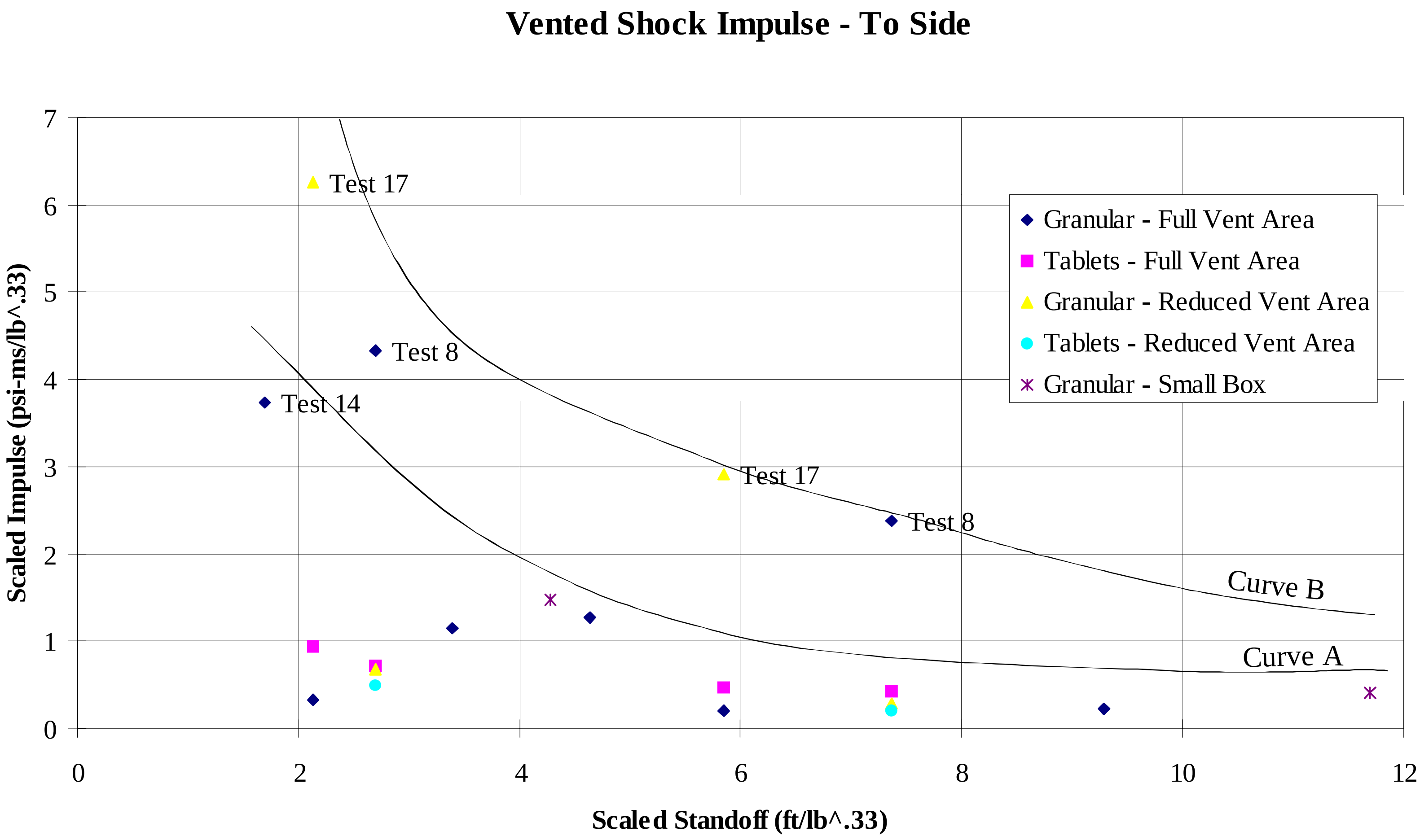

Figure 4.2 Vented Scaled Shock Impulse

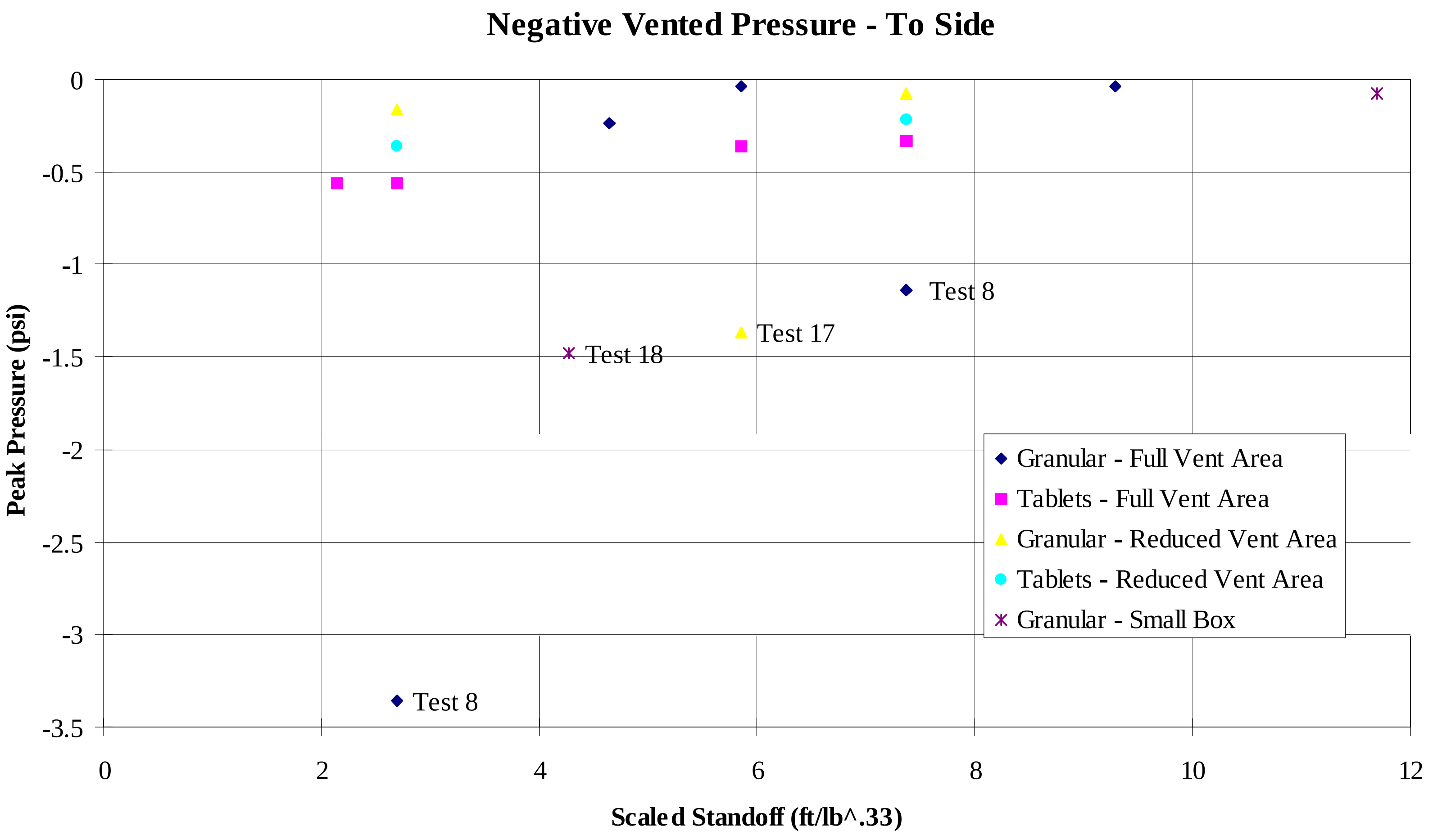

Figure 4.3 External Negative Pressure

5. **Conclusions and Recommendations**

The tests provided a significant amount of beneficial data for better understanding the loads produced by one of the airbag cartridge propellants in operating conditions. However, the data obtained is somewhat limited and contains some scatter. Additional validation would be helpful to gain confidence in applying this information to predicting loads.

In general, the loads generated by hazard classification 1.3 propellants are dependant on the quantity of material involved, the volume of the room confining the propellant, and the vent area. Tests which simulate operating conditions can be performed to quantify these loads. These tests will help to provide the designer with the necessary loading information to design a safe work environment for personnel near these hazardous operations, while avoiding the use of overconservative assumptions for predicting loads.