Prediction of Shock Pressure Histories in Cylindrical Blast Containment Chambers

by

Charles J. Oswald, Wilfred Baker Engineering, Inc.
Edward D. Esparza, Engineering Consultant

A number of containment chambers have been manufactured over the last decade for totally confined testing of high explosive charge weights ranging up to approximately 22 lbs of TNT. Typically these chambers are cylindrical, with a length to diameter ratio between one and two. The chambers are designed to resist blast pressures from the design charge weight without any plastic deformation. This paper discusses how the BLASTX computer code can be used to predict internal blast loads on the chamber walls. This code uses a polygon to model the actual circular cross section of the chamber. A parametric study has shown that the shock pressure history predicted on the chamber endcaps increases with the number of sides on the polygon. Therefore, the predicted blast pressure does not approach a single value as the polygon models the circular cross section more accurately with additional sides. However, comparisons to available data from proof tests on existing containment chambers indicate that blast pressures can be predicted with reasonable accuracy if the number of sides on the polygon is chosen based on the ratio of the charge standoff to the endcap divided by the chamber diameter.

Introduction

Design blast loads for structures subjected to internal blast loading are typically calculated with fast-running computer codes that use a combination of empirical and physics-based relationships to predict blast pressure histories. This approach has been used in several computer codes that calculate blast pressure histories inside rectangular rooms, including the SHOCK[1], FRANG[2], and BLASTX[3] computer programs. These programs have been compared to data from explosive tests in rectangular structures and, based on the comparisons, they are usually considered accurate enough for design purposes.

In recent years, the BLASTX code has been expanded so that it calculates blast pressure histories from detonations in cylindrical rooms. This is especially useful for the design of blast containment chambers, which are typically cylindrical with a length to diameter ratio between one and two. However, the BLASTX code has not been subjected to many comparisons against data from tests in cylindrical rooms. This paper shows such comparisons with data from proof tests conducted in two cylindrical explosion containment chambers and discusses how the current version of the BLASTX code can be used to predict design loads in blast containment chambers.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**

4. TITLE AND SUBTITLE **Prediction of Shock Pressure Histories in Cylindrical Blast Containment Chambers**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Wilfred Baker Engineering, Inc, ,8700 Crownhill Rd,San Antonio,TX,78209-1128**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Discussion of Available Test Data

Blast pressures were measured during proof testing in blast chambers that were built for two DOE facilities, as shown in Table 1. Testing was performed in three identical chambers built for Mound Laboratory and in a single chamber built for Los Alamos Laboratory. Figures 1 and 2 show the two types of chambers. Both steel chambers have a concrete floor and elliptical endcaps. Charges were placed in the geometric center (excluding the door) of the Los Alamos blast chamber during the tests and blast pressures were measured on the chamber sidewalls in the cross section with the charge and at the center of the endcap without the door. Charges were placed at three locations in the Mound blast chambers (locations A, B, and C in Figure 1) and blast pressures were measured at the centers of both endcaps, and at several locations on the chamber sidewalls and floor. C4 charges were used in the proof tests of both types of blast chambers. The TNT equivalent charge weights shown in Table 1 were calculated using a TNT equivalency factor of 1.127 for C4, based on the ratio of the heats of detonation for C4 and TNT. Complete descriptions of the tests are given in References 4 and 5.

Table 1. Summary of Blast Chambers Used for Explosive Proof Tests

Owner	Equivalent TNT Charge Weights (lbs)	Diameter (ft)	Total Length (ft)	Length to Diameter Ratio	Volume (ft^3)	Charge Weight to Volume (lb/ft^3)
Mound Laboratory	2.5 (min) 12.5 (max)	14.5	24	1.65	3000	0.001 (min) 0.004 (max)
Los Alamos Laboratory	5.0 (min) 22 (max)	11.5	21.1	1.83	1500	0.003 (min) 0.015(max)

BLASTX Code Calculations

The BLASTX (Version 3.5) computer code[3] was used to calculate blast pressure histories at the pressure gage locations in the two chambers for the full range of charge weights that were tested. The code uses empirical relationships to get free-field blast pressure histories from the actual charge and from image charges, which account for shock wave reflections off each surface of the room. “Shock addition rules”, based on curve-fits to results from hydrocode runs, are used in the code to combine, or superimpose the effects from multiple blast wave reflections that arrive at the target point at the same time. The code also uses an empirical procedure to account for the Mach stem effect.

The code predicts blast pressures in single and multiple room configurations for rooms with a variety of shapes. It predicts pressures in cylindrical rooms with flat endwalls and length-to-diameter ratios less than approximately 2.0. The code is not intended as a tool for predicting shock pressures in long tunnels since it does not model the coalescence of reflected shocks into a planar shock front. It has been validated against data from a number of explosive tests in single and multiple room configurations for rectangular rooms[3] and against a few tests where shock pressures were measured against the sidewalls of cylindrical tunnels at distances within several tunnel radii of the charge[6].

The cross sections of the two blast chambers were modeled using circumscribed polygons as required by the BLASTX code. This approach is illustrated in Figure 3. The polygon was tangent with the actual cross section at the gage locations, so that the standoff to the pressure gages was preserved. The elliptical endcaps of the two chambers were modeled with flat endcaps that circumscribed the actual elliptical endcaps, so that the distance between the flat endcaps in the models was equal to the total length of the actual chambers. Blast pressures from a maximum of five shock wave reflections off each reflecting surface were included in the analysis.

Ten-sided polygons are used in BLASTX example problems to model circular cross sections, but no specific criteria for modeling circular cross sections is provided. Therefore, a parameter study was performed with the Mound blast chamber where multiple BLASTX computer runs were made that were identical except for the number of sides used on the circumscribed polygon used to model the circular cross section. The polygons were characterized by the segment angle (out of 360 degrees) used to define their chords or segments. For example, a 30 degree segment angle corresponds to a twelve sided polygon if there is no floor in the chamber. Since there are concrete floors in both types of chambers, the floors were modeled with a straight line across the cross section at the floor height and the other sides of the polygon were defined using the segment angle. The charge was located at the center of the chamber.
.
The number of sides did not affect the peak shock pressures and impulses calculated on the sidewalls and floor in the parameter study, which were dominated by the initial blast wave and the first shock wave reflection off the floor. However, this was not true for pressure histories calculated on the endcaps of the chamber. Figure 4 shows shock pressures that were calculated on the center of the endcap of the Mound chamber for a 12.5 lb charge weight, detonated at the center of the chamber, using differing numbers of sides on the polygon circumscribing the cross section. The predicted peak shock pressure and impulse both continue increasing as the polygon matches the actual circular cross section more closely with smaller segment angles, rather than asymptotically approaching single values.

This is due to increased pressure in the second pulse of the pressure history. The pressure in the second pulse is caused by the first reflection of the shock wave off each of the sides of the polygon-shaped cross section and these reflections are focused towards the center of the endcap by the geometry of the chamber. The target for the calculated pressure histories in Figure 4 is within the Mach stem region caused by the reflection of the shock wave off the concrete floor. The BLASTX code models each reflection with a separate image charge, so that the number of image charges increases with the number of sides used on the polygon modeling the cross section. A certain number of image charges are necessary within the algorithm used by BLASTX to account for the energy from the blast wave that reflects off the walls and is contained within the chamber. However, as the number of sides on the polygon increases, the number of image charges increases until the combined energy from the image charges apparently overcompensates for the actual energy that is contained in the cylinder by the reflection of the shock wave off the sidewalls. Thus, the calculated blast pressures from the reflected shock waves increase to unrealistically high values.

The shape of pressure histories predicted by the BLASTX code in Figure 4 are similar to pressure histories measured at the center of endcaps on cylindrical blast chambers, although they do not contain the fine detail in the measured histories. The peak pressure and most of the impulse occur in the second pressure pulse in the measured pressure histories, just as they do in the calculated pressure histories.

Comparison of Blast Pressures Calculated with BLASTX to Measured Values in Blast Containment Vessels

Figure 5 summarizes a comparison between peak shock pressures and impulses measured during proof testing on the sidewall and floor gages of both types of blast chambers and corresponding values predicted by the BLASTX code. As stated previously, the type of polygon used to represent the circular cross section does not affect the peak pressures and impulses calculated on the sidewalls and floor, since they are dominated by the initial blast wave and the first shock wave reflection off the floor. This study shows that BLASTX tends to overpredict impulse and underpredict peak pressure for these targets. On the average, the predicted peak pressure is equal to 80% of the measured value and the predicted impulse is equal to 110% of the measured value. This is consistent with a previous comparison between BLASTX and pressure histories measured during testing in a rigid rectangular box structure which calculated corresponding percentages of 90% for peak pressure and 145% for impulse[7]. However, it must be pointed out that higher peak pressures would be predicted if the explosive was input into the BLASTX code as C4 explosive with the actual charge weight because the BLASTX code uses a higher TNT equivalency factor for C4 explosive than that assumed in this study.

Figure 5 is based on calculated shock pressure histories that do not include any quasistatic pressure. The peak pressures and impulses measured during the Mound chamber tests are taken from Reference 4, which reports the impulse over the first 8 milliseconds after arrival of the shock wave. Typical measured pressure histories in the report show that this time interval does not include any significant quasistatic pressure. Measured impulses from the Los Alamos chamber tests were read from pressure histories at the end of 3 to 5 milliseconds, so that they included the effects of the primary shock pressure pulses but did not include any significant quasistatic pressures. BLASTX impulses were read off calculated pressure histories at corresponding times. Figures 6 and 7 show the blast pressure history measured during the 22 lb proof test in the Los Alamos chamber on the sidewall directly across from the charge and the corresponding prediction with BLASTX.

Since peak pressure and impulse on the endcap are sensitive to the number of sides on the polygon modeling the chamber cross section, another parameter study was performed that compared measured and calculated pressure histories on the endcap of the Mound Laboratory blast chamber. This parameter study compared measured peak pressure and impulse values to values calculated using polygon segment angles of 30, 15, and 7.5 degrees for charge weights over the full range shown in Table 1, detonated in the center of the chamber. This study showed that the impulse values predicted at the center of the endcap using the 30 degree segment angle matched measured values the best. However, for this segment angle the calculated peak pressures underpredicted measured values by a factor of approximately 2.0. The smaller segment angles caused predicted peak pressures on the endcap to match measured values better, but caused the impulse to be overpredicted by a very significant amount.

Figure 8 summarizes a comparison between peak shock pressures and impulses measured at the center of the endcap and corresponding predicted values for the two cylindrical blast containment chambers that were proof tested. The charge was located in the center of the blast chambers for all the data points shown in Figure 8, so that the ratio of gage standoff (R) to chamber diameter (D) was between 0.5 and 1.0. A segment angle of 30 degrees was used for the polygons circumscribing the cross sections in the BLASTX models of the Mound and Los Alamos blast chambers.

As Figure 8 shows, the measured peak pressure values at the center of the endcap are underpredicted by BLASTX, and the impulse is overpredicted, following the same trend shown in the comparison at the sidewall and floor targets. However, on the average in this case the predicted peak pressure is equal to 70% of the measured value and the predicted impulse is equal to 130% of the measured value. Figures 9 and 10 show the blast pressure history measured at the center of the endcap during the 22 lb proof test in the Los Alamos chamber and the corresponding pressure history predicted with BLASTX.

The 30 degree segment angle seems to cause the correct amount of energy to be focused on the endcap in the BLASTX calculations, as evidenced by the relatively good match with measured impulse values, but the duration of the second pulse in the pressure history (i.e. the largest pulse on the endcap) is overpredicted. This causes the peak pressure to be underpredicted. It is possible that an approach which preserves the total summed weight of the image charges for the case where the polygon has 30 degree segment angles, but distributes this total weight into smaller image charges around a polygon with more sides, would be preferable. This approach will probably still predict the impulse well, since it uses the same total weight of image charges as a polygon with 30 degree segment angles. However, it would predict a second pulse with a higher peak pressure and shorter duration since it would superpose a larger number of pulses with shorter durations. Since the total weight of the image charges would remain fixed, this approach should also result in a peak pressure and impulse that asymptotically approach single values as the number of sides on the polygon increases and represents the circular cross section more accurately.

For four off-center tests in the Mound chamber, where the charge distance to the far endcap was such that $1.0 < R/D < 1.5$, the impulse calculated using a polygon that circumscribed the circular cross section with 7.5 degree segment angles matched measured impulse and peak pressures in a manner similar to that shown in Figure 8. Thus, the 30 degree segment angle is not always the best value to use for a polygon representing the cross section of a cylindrical room and it seems from the limited available data that the optimum segment angle to use is a function of R/D. This is significant because it also shows how carefully the calculation procedure must be validated against representative test data when using BLASTX to predict pressure histories on the endcaps of cylindrical blast chambers.

Prediction of Design Blast Loads in Cylindrical Blast Chambers with the BLASTX Code

The best overall agreement between measured pressure histories in the two cylindrical blast containment chambers and those calculated with the BLASTX (Version 3.5) code was achieved when a circumscribed polygon with 30 degree segment angles was used to represent the cross sections of the chambers. This was true for the typical design configuration where the explosive charge was detonated in the center of the chamber. Figures 5 and 8 show that, when this approach was used, BLASTX predicted the shock impulse on the sidewalls and endcaps of the chambers fairly well. All the other aspects of measured pressure histories in the two containment chambers were not predicted as well, but they could be modified with multiplication factors to provide blast load information that is considered accurate enough for typical design requirements. The calculated shock pressure histories on the sidewalls of the chamber (summarized in Figure 5) may be accurate enough for design purposes, although the peak pressure can be increased by a factor of approximately 1.3, with no change in the impulse, to obtain design peak pressure values that match measured values better. It is very doubtful that an increase factor would be required if the TNT equivalency factor for C4 explosive in the BLASTX code was used in the study. However, blast chambers are typically designed for an equivalent TNT weight and it is conservative for the designer to assume that a lower TNT equivalency factor will be assumed by the users of the chamber. The calculated peak pressure on the endcap should be increased by a factor between 1.5 and 2.0, with no change to the impulse of the second pulse, to obtain a design shock pressure history with a peak shock pressure and impulse that will usually be conservative. This modification will also reduce the duration of the second pulse in the design shock pressure history, causing it to be more similar to typical measured pressure histories on the endcap.

This type of approach can be used to develop design pressure histories because Figures 5 and 8 show that BLASTX predicts the peak shock pressure and impulse in a fairly consistent, reliable manner relative to measured values. Therefore, the proposed multiplication factors should be applicable for the actual design case, assuming that the geometry and charge weights of the Mound and Los Alamos chamber proof tests are representative of the design case. The design pressure history in the chamber should also include the quasistatic pressure.

Recommendations and Conclusions

The BLASTX computer code models explosions in rooms with a wide variety of configurations, including cylindrical blast containment chambers, and provides blast loading information that is very difficult to determine using any other available design-oriented methods. However, the code must be used with caution when predicting pressure histories in cylindrical chambers. The peak shock pressure and impulse predicted on the endcaps of such chambers both increase, rather than converge, as the number of sides on the polygon used to approximate the circular cross section increases. This is apparently due to the inadequacy of the image charge approach currently embedded in BLASTX for cases were a large number of short sides, and thus reflecting surfaces, are used to model shock wave reflections off the cross section of a room.

However, the comparisons shown in this study indicate that BLASTX can be used to predict pressure histories in cylindrical blast containment chambers if the BLASTX modeling procedure is validated against relevant data. Some trial and error was required, but a modeling procedure was determined that calculated pressure histories which compared with measured values in two different blast containment chambers in a fairly consistent and predicable manner. Even though the calculated pressure histories do not match all aspects of the measured pressure histories well, they could be modified with a multiplication factor on the peak pressure to provide blast load information that is considered accurate enough for typical design requirements. In this sense, the BLASTX code functions as an interpolation tool, where the code calculates pressure histories that relate to measured values in a predictable manner within a given range of variables.

References

1. Anon., “SHOCK Users Manual,” Version 1.0, Naval Civil Engineering Laboratory, Port Hueneme, CA, January 1988

2. Wager, P., Connett, J., “FRANG User’s Manual,” Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1989.

3. Britt, James R., Lumsden, Matthew G., “Internal Blast and Thermal Environment for Internal and External Explosions: A User’s Guide for the BLASTX Code, Version 3.0., by Science Applications International Corp., Report No. SAIC 405-94-2., May 1994.

4. Esparza, E.D. and White, R.E., “Blast Pressure Measurements in Containment Test Cells,” 23rd Department of Defense Explosives Safety Seminar, 1988.

5. Esparza, E.D., “Proof-Tests and Data Report for the LANL M-9 Firing Facility Containment Vessel,” Southwest Research Institute Project 06-4023, 1992.

6. Private communication with James R. Britt, May 1996.

7. Bowles, P.M., Oswald, C.J., Vargas, L.M., and Baker, W.E., “Building Debris Hazard Prediction Model,” Southwest Research Institute Project No. 06-2945, Prepared for Bernard Johnson, Inc., U.S. Government Contract DE-AC04-76DP-00487 and Mason& Hanger - Silas Mason Co., Inc. Contract H0760103, February 1991.

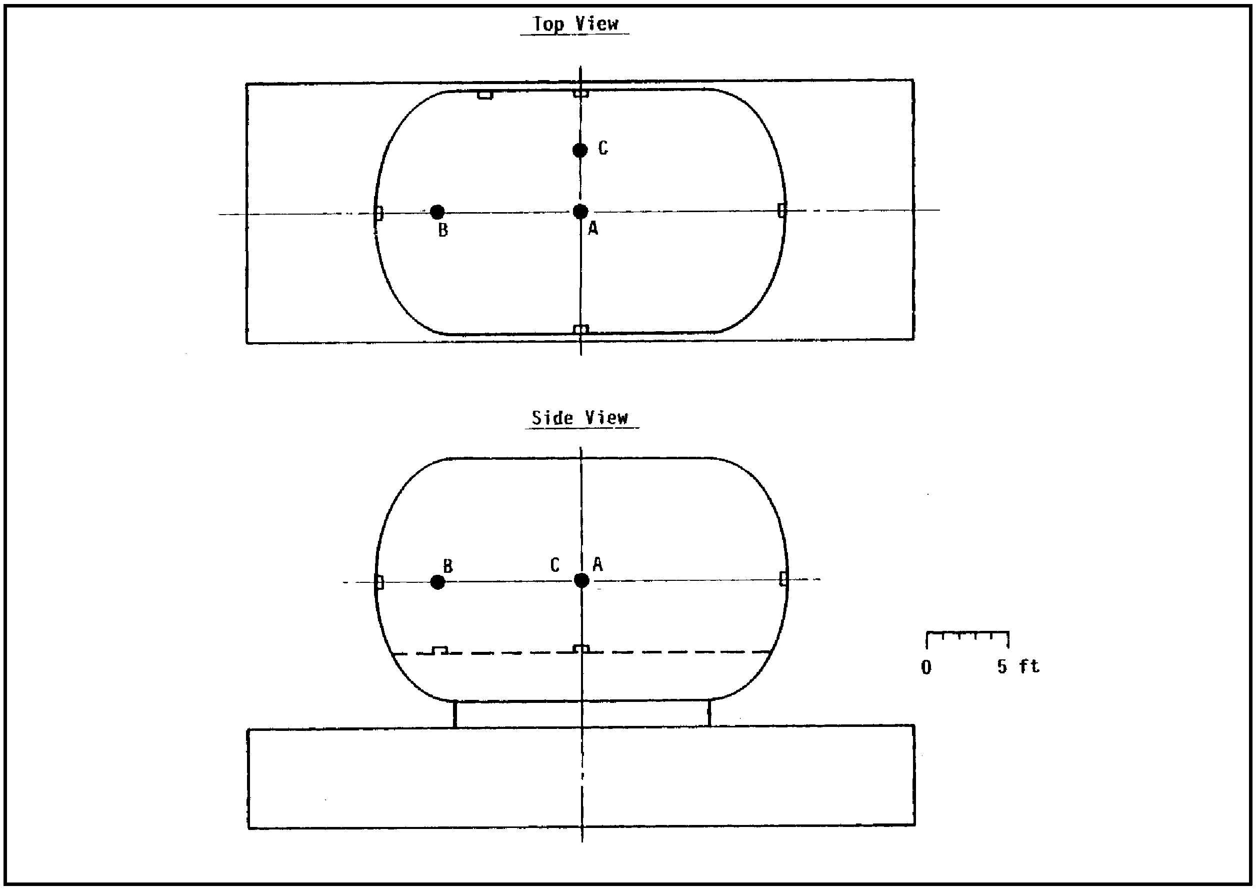

Figure 1 Mound Laboratory Explosive Containment Chamber

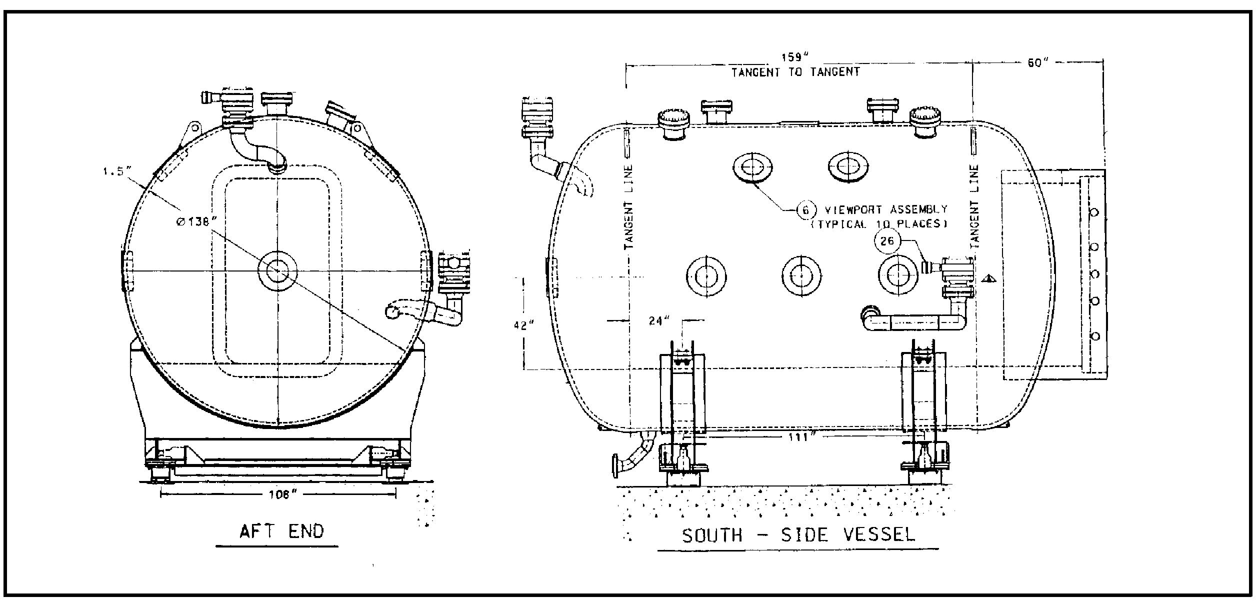

Figure 2 Los Alamos Laboratory Explosive Containment Chamber

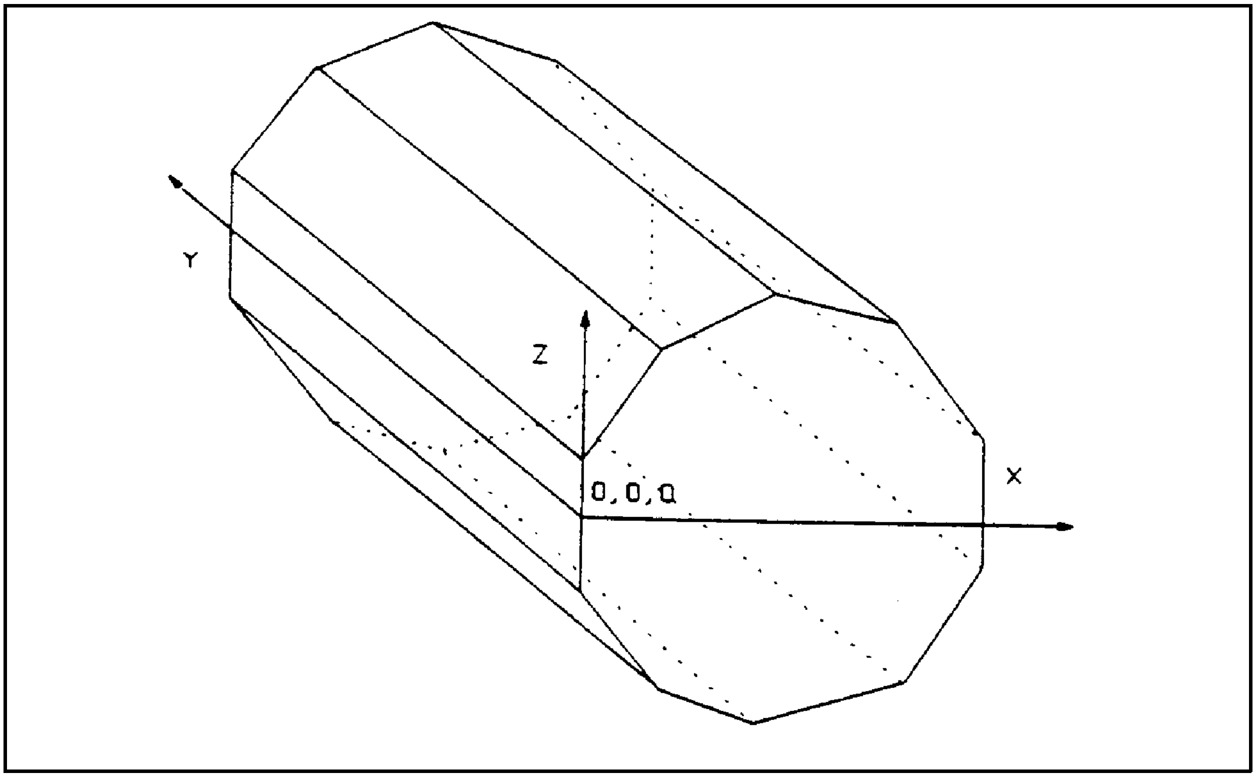

Figure 3 BLASTX Model of Cylindrical Room

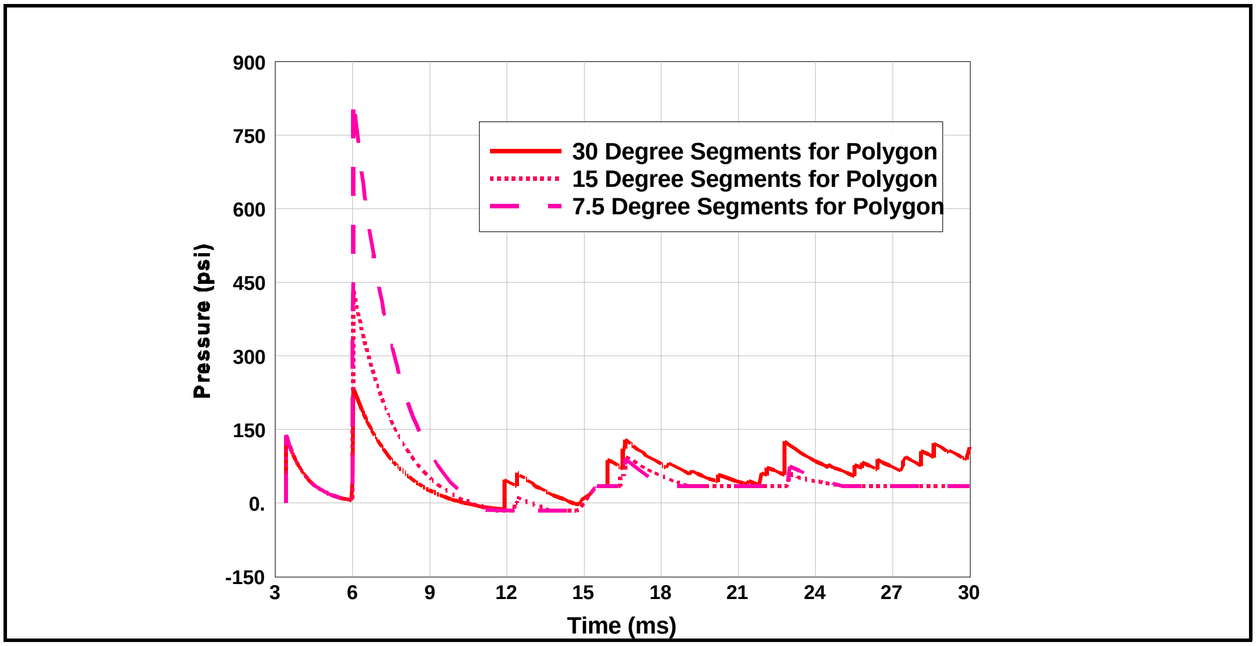

Figure 4 Comparison of Pressure Histories Calculated on the Endcap of the Mound Chamber for Different Polygons Around the Cross Section

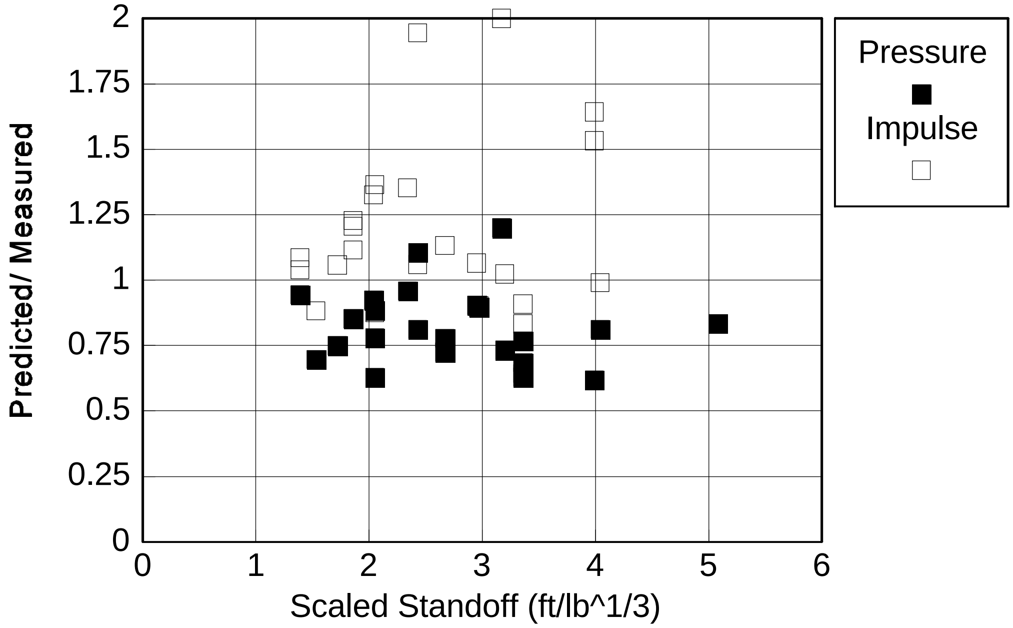

Figure 5 Comparison of Predicted and Measured Peak Pressures and Impulses

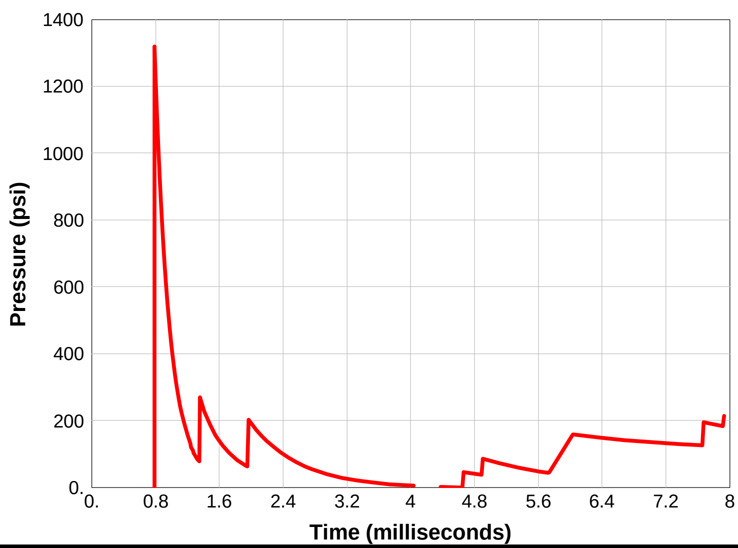

Figure 6 Calculated Pressure History on the Sidewall of Los Alamos Chamber in Cross Section with 22 lb Charge

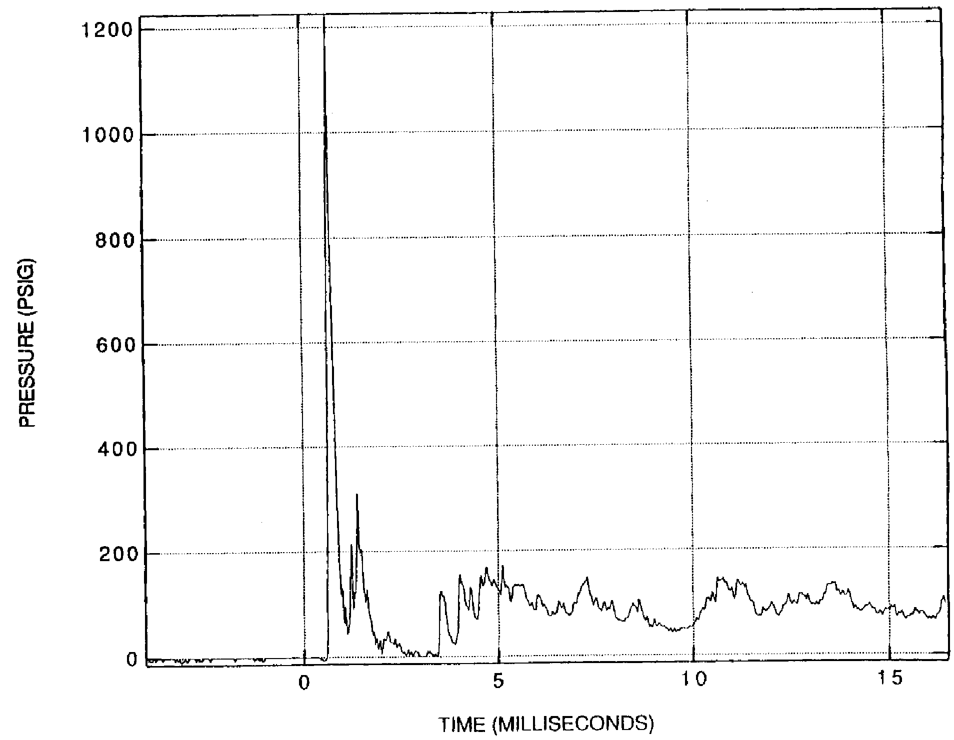

Figure 7 Measured Pressure History on Sidewall of Los Alamos Chamber in Cross Section with 22 lb Charge

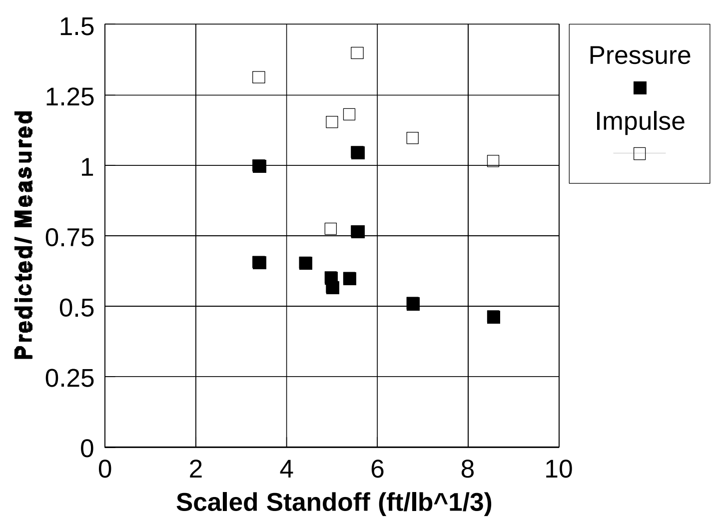

Figure 8 Comparison of Measured and Calculated Peak Shock Pressure and Impulse on Center of Endcap of Cylindrical Blast Chambers

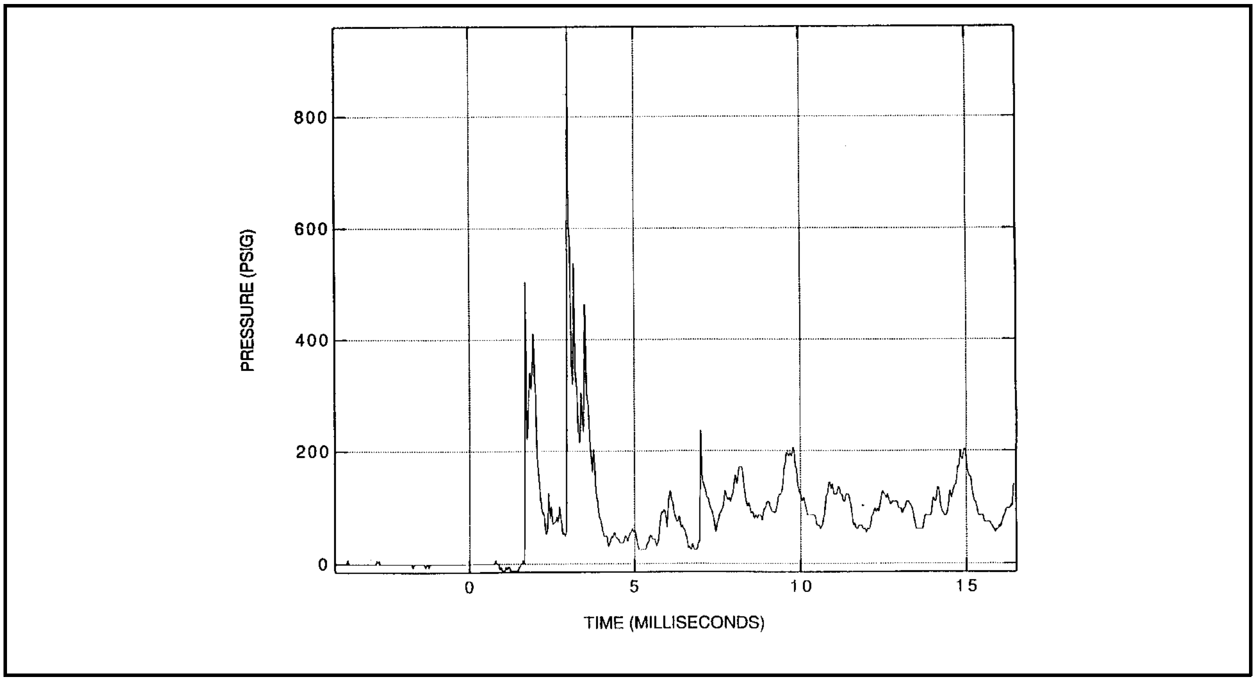

Figure 9 Measured Pressure History on Center of Endcap of Los Alamos Chamber for 22 lb Charge

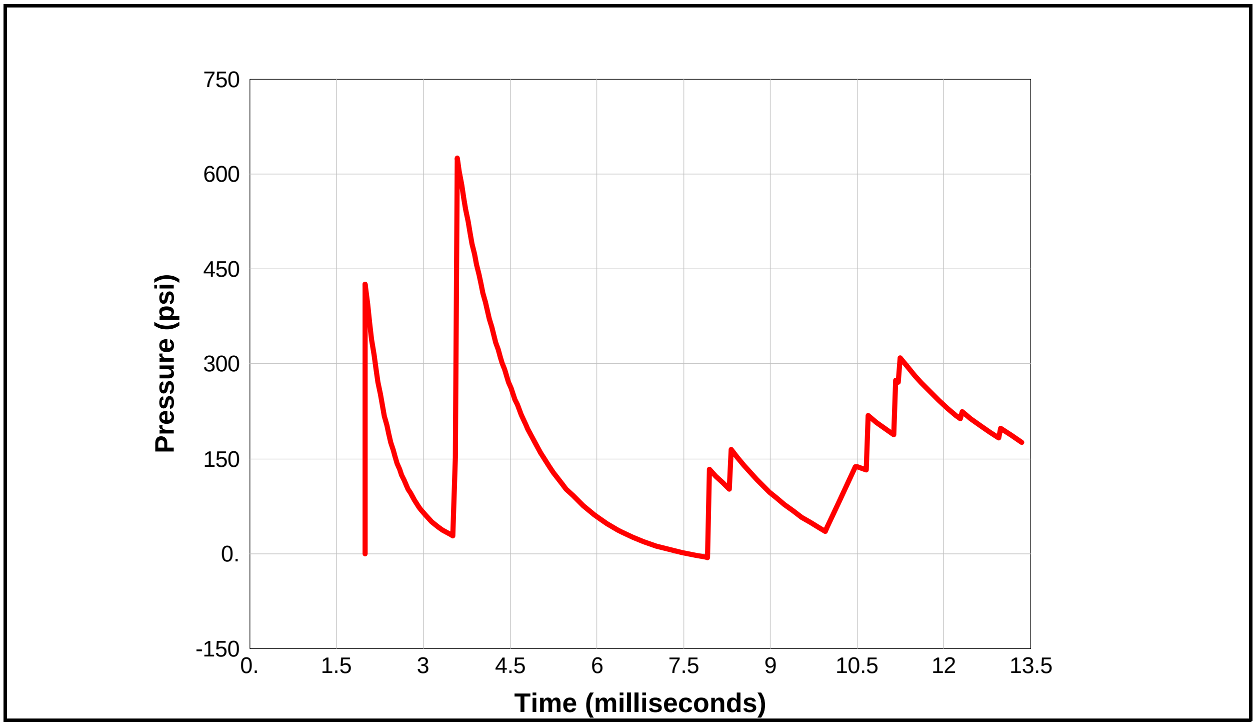

Figure 10 Calculated Pressure History on Center of Endcap of Los Alamos Chamber from 22 lb Charge