Measurement of Blast Reflected Overpressure at Small Charge Standoff with Tourmaline Piezoelectric Transducers

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Presentation Outline

- TSL and EEL Overview
- Objective
- Literature Survey
- Test System and Setup
- Test Results
- Conclusions

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Explosive Effects Laboratory (EEL)

Mission: The Explosive Effects Lab performs fundamental research to characterize improvised explosive devices and their effects on structures.

Focus:

- Research Area 1: Blast response testing and measurement
- Research Area 2: Explosive characterization & equivalency testing
- Research Area 3: Blast response modeling & simulation
- Research Area 4: Blast effects mitigation

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Objective of the Study

Conduct explosive tests to measure blast reflected overpressure and impulse at small charge standoff using tourmaline piezoelectric transducers.

Overpressure and Impulse are important and useful parameters for quantifying:

- blast intensity
- characterizing the blast loading of structures
- assigning explosive equivalence.

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Literature Survey

Previous Small-Standoff Measurement Studies

Authors	**Year**	**Test Method**	**Charges** (Pentolite spheres)	**Standoff (inches)**	**z (ft/lb$^{1/3}$)**
Johnson et al. [3]	1957	Impulse Plug	1/2 – 2 lb	5 - 38	0.5 - 2.5
Huffington and Ewing [4]	1985	Impulse Plug	1/2 – 2 lb	1.4 - 7.5	0.15 – 0.5
Hoffman and Mills [6]	1956	Tourmaline Gages	1/2 – 8 lb	23-161	1.48 - 14.81
Jack [7]	1963	Tourmaline Gages	1/8 lb	3 - 39	0.5 - 6.5

Literature Survey (contd.)

Impulse Plug Measurement

- Utilize the final velocity of an unrestrained cylindrical plug, ejected from a hole in a large rigid steel plate, to measure reflected blast impulse
- Previous efforts provide a comprehensive set of reflected impulse data for standoff distances from near contact out to several feet
- Method yields impulse only – not blast pressure history

Literature Survey (contd.)

Reflected Blast Pressure Measurements

- Numerous attempts to use piezoelectric transducers at close range
- Transducer response is increasingly dominated by oscillatory noise as the charge standoff is reduced
- At small distances the recorded pressure histories of nominally identical tests showed large variability and none of the histories exhibited the sharp pressure rise followed by exponential decay that is typically observed at larger scaled distances.

Literature Survey (contd.)

Reflected Blast Pressure Measurements (contd.)

- Jack (1963) measured normally reflected pressures up to nearly 30,000 psi for 1/8 pound Pentolite spheres over a scaled distance range of 0.5 to 6.5 ft/lb$^{1/3}$ using tourmaline-based piezoelectric pressure gages
- Morozov et al. (1992), using shadowgraph techniques, determined that the cloud of detonation products can extend out to between 20 and 30 charge radii

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Literature Survey (contd.)

Key Challenges to Blast Pressure Measurement at Small Standoff

- Severe ringing of the response at close range, probably related to resonant excitation of the transducer
- Transducer operation within the cloud of detonation product gases
- Gage-to-gage and shot-to-shot response non-uniformity

Test System and Setup

Selected transducers selected for these tests are PCB model 134A02 due to their high resonant frequency (1.5 MHz).

Measure reflected blast pressure at near normal incidence and standoff distances from 5 to 25 inches from the center of detonating half-pound spherical C-4 charges.

Photo from http://www.pcb.com/spec_sheet.asp?model=134A27&item_id=10839

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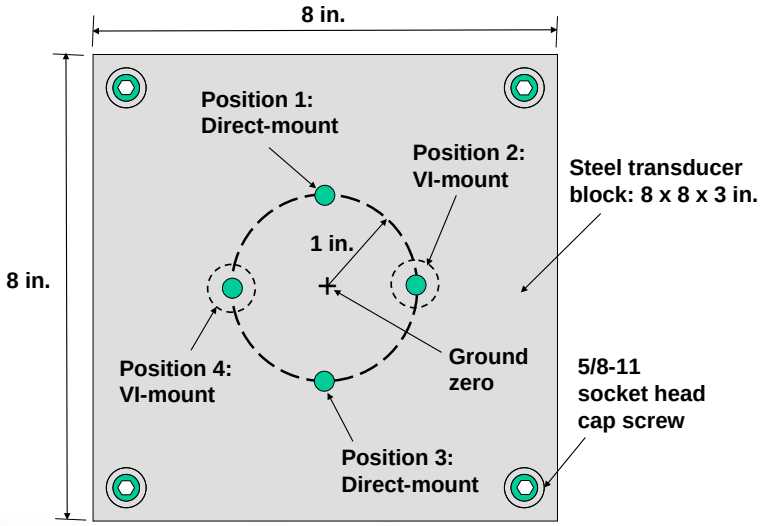
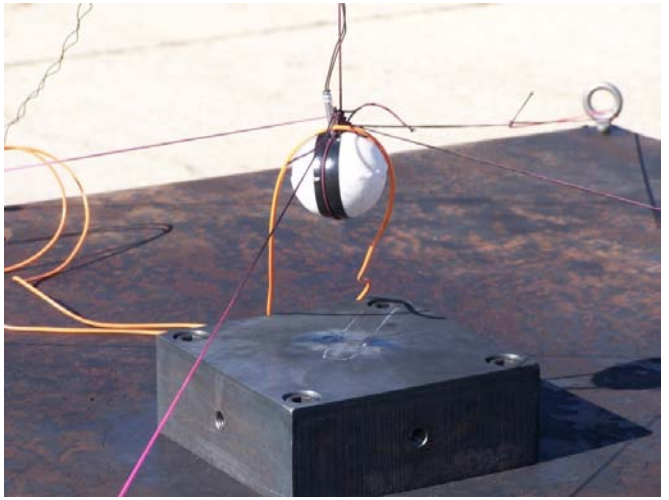
Test System and Setup (contd.)

An array of four pressure transducers installed in a concentric pattern with sensing faces mounted flush to the upward-facing horizontal surface of a rectangular steel transducer block.

Two of the transducers were threaded directly into the steel transducer block. The two remaining transducers were mounted with vibration isolation.





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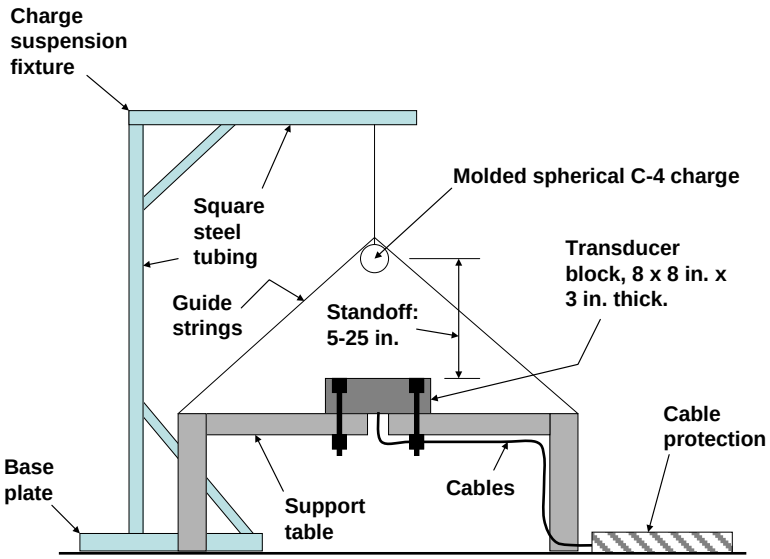
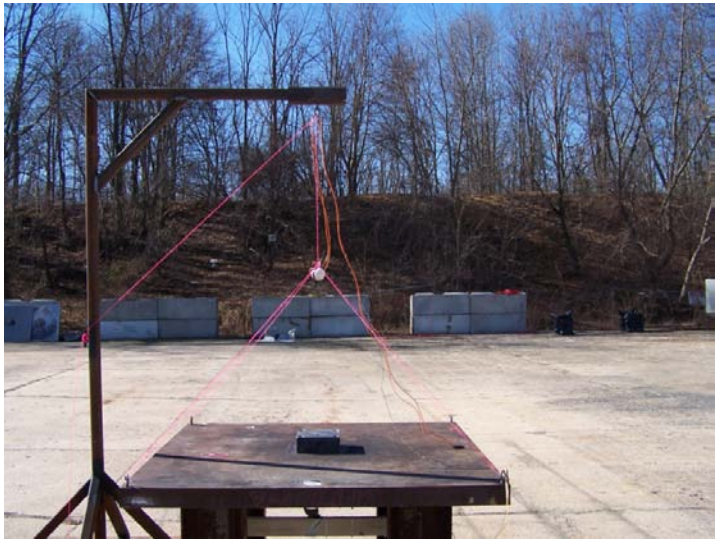
Test System and Setup (contd.)

Transducer block was rigidly mounted at the center of a massive steel support table





Test System and Setup (contd.)

The sensing face of each of the four transducers was recessed about 0.5 mm below the surface of the transducer block and coated with either Dow Corning 340 heat sink compound or silicone grease heavily doped with graphite powder in order to reduce transducer thermal response.

In some tests a piezo-pin was installed vertically in a narrow drilling in the block at the ground zero position to sense blast wave arrival time. In some of the tests a second piezo-pin was installed in the charge to sense detonation, independent of the fiber optic break-wire for triggering data acquisition.

Each pressure transducer was coupled to a PCB 402A03 charge converter and connected to the Data Acquisition System (DAS). A 10 MHz data sampling rate was used. Data collection continued for 2 ms after the DAS was triggered.

Charge Radii and Scaled Distance

	Near-Field Limits for 0.5 lb C-4		Standoff	
	R_{min} = 1.83 in.	R_{max} = 4.66 in.	5 in.	25 in.
Charge radii*	1.44	3.68	3.95	19.7
z [ft/lb$^{1/3}$]	0.192	0.489	0.525	2.62
z_{TNT} [ft/lb-TNT$^{1/3}$]	0.176	0.451	0.484	2.42

*1.267 in. charge radius for 0.5 lb C-4

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Test Results

A total of 32 tests were carried out with charge standoffs of 5, 7.5, 12.5, 17.5, and 25 inches to ground zero on the transducer block.

Present pressure transducer arrival times and ground zero (piezo-pin) arrival times

Present raw peak pressure and raw impulse and fitted peak pressure and fitted impulse (Friedlander curve).

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Test Data Summary

		Responses		
Standoff	Tests	Pressure	Pin on Block	Pin on Charge
25	9	35/36	5	1
17.5	6	21/24	3	1
12.5	6	20/24	5	1
7.5	6	17/24	5	1
5	5	20/20	2	1

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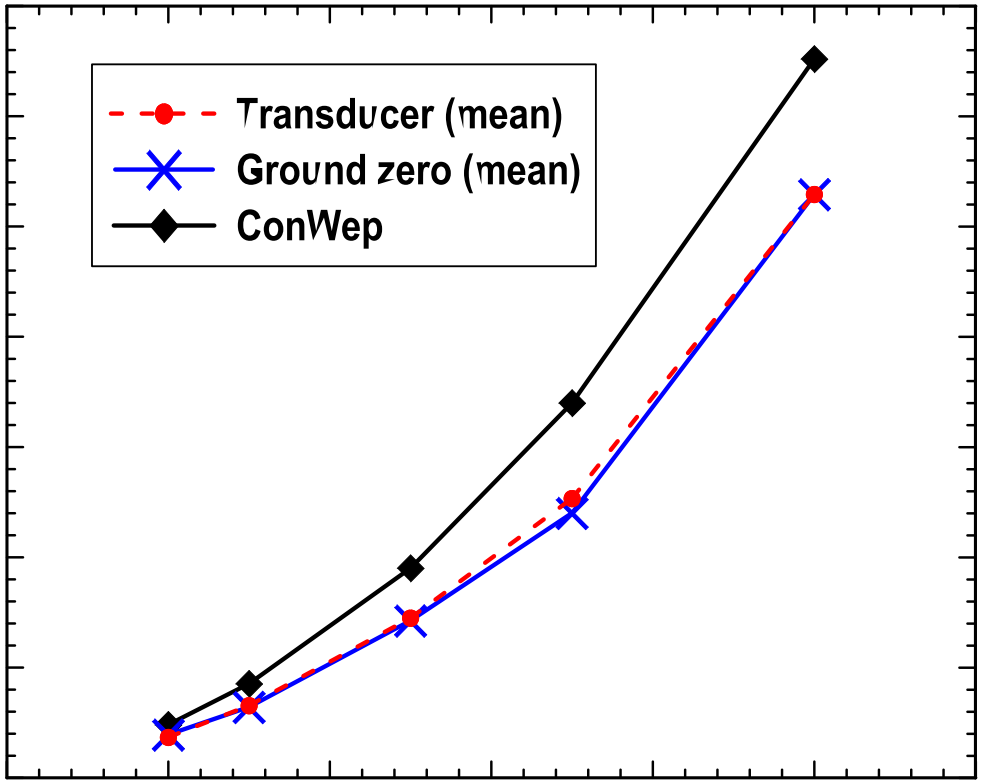
Blast Wave Mean Arrival times



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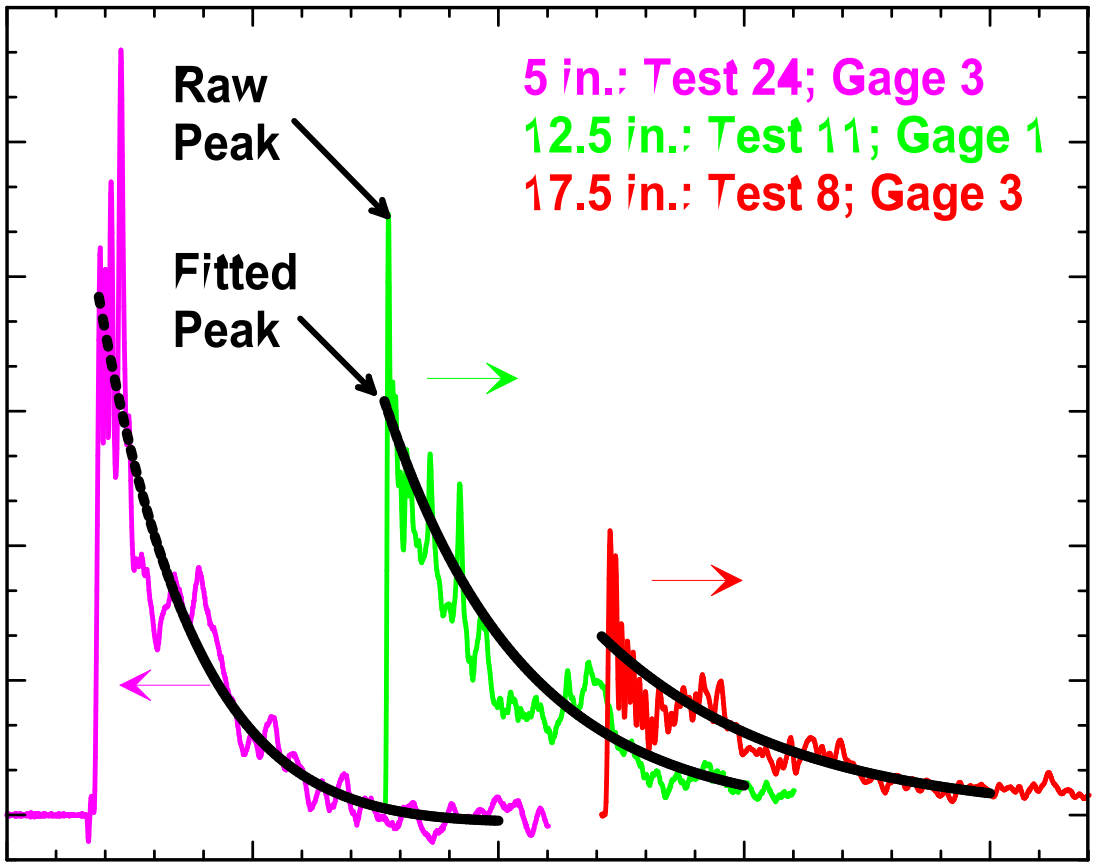
Raw and Fitted Overpressure Curves



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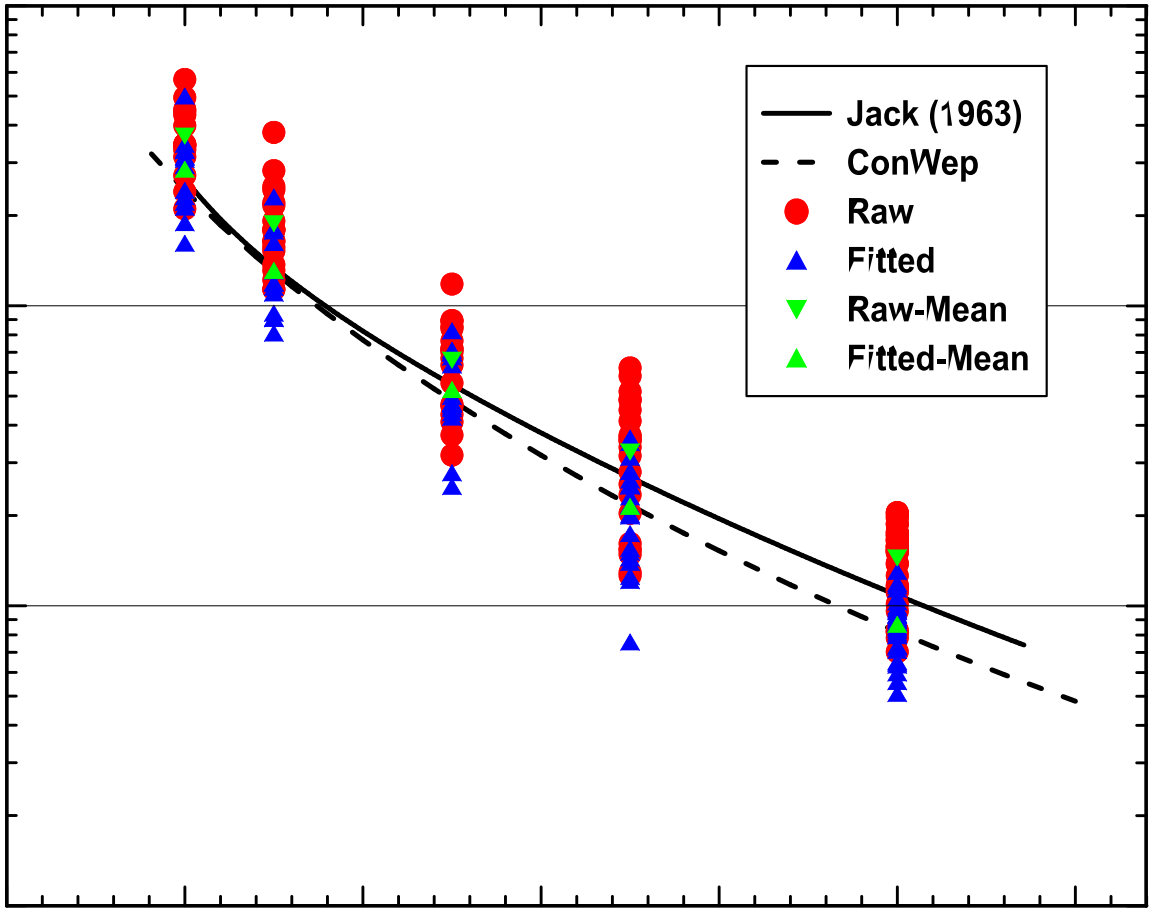
Peak Reflected Overpressure



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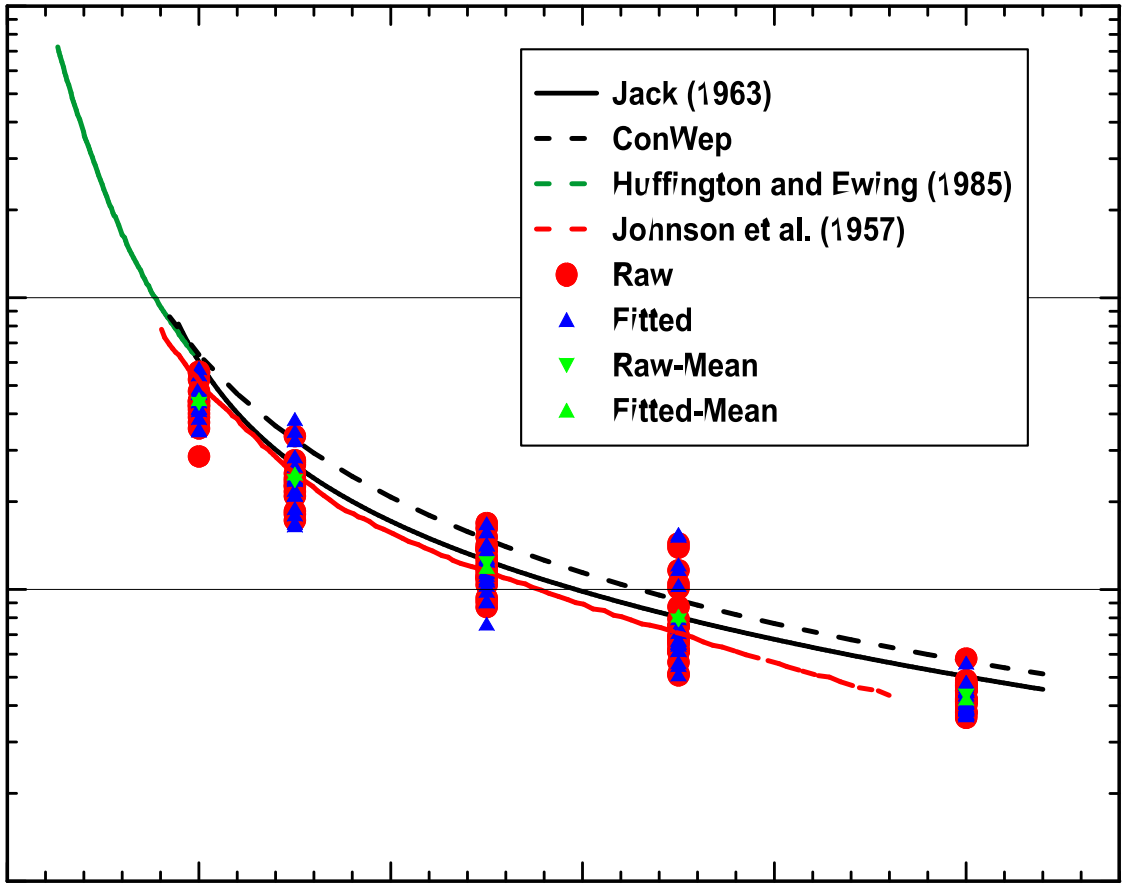
Reflected Impulse



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Mean Raw and Fitted Data

Standoff [in.]	Tests	Gages	Pressure* [psi]		Impulse* [psi-ms]	
			Raw	Fitted	Raw	Fitted
25	9	35	1451 (387)	867 (81.7)	43.5 (4.3)	42.3 (4.2)
17.5	6	21	3270 (1506)	2143 (794)	78.6 (25.8)	81.3 (30.4)
12.5	6	20	6616 (2268)	5257 (1567)	124 (22.7)	119 (23.1)
7.5	6	17	18,854 (6634)	13,099 (4431)	236 (44.0)	249 (62.6)
5	5	20	36,954 (9699)	28,523 (8525)	435 (73.3)	449 (62.9)

Data Comparison

Standoff [in.]	Peak Pressure [psi]			Impulse [psi-ms]		
	Present (Fitted)	Jack	ConWep	Present (Fitted)	Jack	ConWep
25	867	1132	819	42.3	52.7	56.7
17.5	2143	2640	2166	81.3	80.8	91.8
12.5	5257	5472	4834	119	121	149
7.5	13,099	13,641	12,990	249	274	325
5	28,523	26,404	24,270	449	620	637

Conclusions

For standoff less than 25 inches, measured pressure histories exhibited considerable variability in the gage-to-gage sense for a given test and in the shot-to-shot sense for a particular gage.

This non-uniformity was observed undiminished in the peak pressure data, but to a lesser degree in the impulse data due to averaging of the response oscillations by the integration process.

Peak reflected pressure ranged from about 900 psi at 25 inches to more than 28,000 psi at 5 inch standoff.

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Conclusions (contd.)

The present peak pressure measurements agree with:

- ConWep predictions within 15%
- Early BRL/Aberdeen measurements to within 5-30%

Impulse measurements deviate from:

- ConWep and early BRL data by 15-40%.

It is believed that the tourmaline transducers used here may be useful for pressure testing at small charge standoff provided that a sufficiently large number of tests are performed to reduce the measurement uncertainty to an acceptable level.

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