MEASUREMENT OF HEAD AND CHEST ACCELERATIONS DURING BOMB BLAST TESTING

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ABSTRACT

The dangers involved with handling explosives and other incendiary devices are well known. Injuries can include, but are not limited to overpressure, fragmentation, impact, and heat injury. To investigate blast injury phenomenon, a series of 30 tests was conducted on an instrumented anthropomorphic test dummy with and without protective clothing. Head and chest acceleration measurements were obtained for twenty-three of these trials. The results indicate that rapid head and chest movement following the blast wave can cause significant accelerations. These accelerations can be even more pronounced in the event of impact into a solid surface. Reduction of these potentially injurious accelerations can be realized through the use of proper protective equipment.

INTRODUCTION

Any type of blast injury is often serious and in some instances, fatal. Previous investigations (1,2,3)[1] have shown that overpressure, fragmentation, impact, and heat injury are major threats during explosive blasts. However, at the present time the exact nature of some of these mechanisms of injury is not well understood. This is partly due to the fact that human injury in bomb blast situations is very much a function of many dependent and independant variables.

Clinical research has provided a great deal of information regarding the types of injuries that are sustained during blast situations. One particular study (3) documented injury data from 5600 blast incidents involving 495 fatalities. It was shown that 66 percent of the fatalities involved some form of brain damage while 51 percent sustained skull fracture. It was also noted that 49 percent suffered brain damage with associated skull fracture; while 16 percent experienced brain damage without skull fracture. The former would perhaps suggest that head injury in blast situations may be partially due to direct impact (into a solid surface). The latter would suggest the inertial acceleration of the brain due to the blast pressure wave impact.

Previous experimental research has been conducted using animals and anthropomorphic test dummies (4,5,6,7). As a result, considerable information has been obtained regarding human tolerance to air blast effects.

The authors are not presently aware of published research that has included monitoring acceleration response of an anthropometric test dummy following a bomb blast. This paper shall describe acceleration test results obtained during bomb blast testing in an effort to better understand impact injury in blast environments.

METHODS AND PROCEDURES

All blast testing was performed at one of the artillery ranges at Canadian Forces Base Borden. The test site consisted of a large, flat sandy area upon which a series of flat steel plates were placed to create a solid impacting surface approximately four metres wide and twelve metres long. The use of the steel plates simulated a worst case situation with maximized pressure wave reflections. All blast tests except two were carried out on this surface. The remaining two tests were conducted adjacent to the steel plates on the flat sand surface.

The explosives used ranged in mass from 2 kg to 8 kg and were tightly bundled using sticks of 75% forcite dynamite. The charges were placed 3 metres in front of the test dummy and supported by a polyurethane foam block.

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[1] Numbers in parentheses designate references at the end of paper.

The anthropomorphic test dummy (pedestrian model) was positioned upright with the aid of two steel posts supporting the upper body of the dummy (see figure 1). The protective suit worn by the test dummy consisted of a suit and helmet manufactured specifically for bomb blast protection (see figure 2).

The full coverage helmet consisted of an impact attenuating liner with a composite shell. A thermoplastic laminate visor was located on the front of the helmet. The suit was fabricated from polyaramid material with solid composite insert pieces for additional protection to the thoracic and abdominal regions.

The dummy was fitted with three uniaxial accelerometers mounted orthogonally inside the head and a triaxial accelerometer mounted in the chest cavity of the test dummy. The accelerometer signals were carried through a series of 100 metre cables into a protective concrete bunker. Inside the bunker, each channel was amplified and conditioned before it was analog to digital (a/d) converted at a rate of 10000 Hz per channel using a personal computer with a/d hardware. Free field blast guages were located one meter above the ground at a distance of three metres from the center of the explosive charge. The voltage from these guages was recorded using a digital oscilliscope. Additional pressure transducers were located on the head, chest and groin of the test dummy. The results obtained from these transducers shall not be discussed in this paper.

Prior to each test, the dummy was inspected for damage and positioned using the steel posts. The dynamite charge was placed on the foam block and a detonator was inserted into the charge. A fibre optic trigger was also placed at the centre of the charge. It was this trigger that activated the a/d system which collected the acceleration signals. Upon detonation, the six acceleration signals were displayed and subsequently stored on the hard disk of the computer.

A pair of non-blast tests were also conducted during this test series. These tests consisted of manually pushing an unclothed, instrumented test dummy from a standing position towards the steel plates. Data collection was triggered manually during these tests.

Upon completion of the testing, all available trials were downloaded onto floppy disks. All channels were then calibrated and the bias was removed. Each head accelerometer channel was then filtered using an SAE Class 1000 digital filter. Each chest acceleration channel was filtered using an SAE Class 60 digital filter.

Resultant head accelerations were calculated and plotted for analysis with maximum and minimum accelerations obtained for each axis. Whenever possible, peak resultant head accelerations and chest accelerations were obtained for both the initial blast wave as well as the secondary impact resulting from impact onto the steel plates. Chest accelerations were then plotted for analysis with maximum and minimum accelerations obtained for each axis.

Figure 1: Experimental Test Dummy.

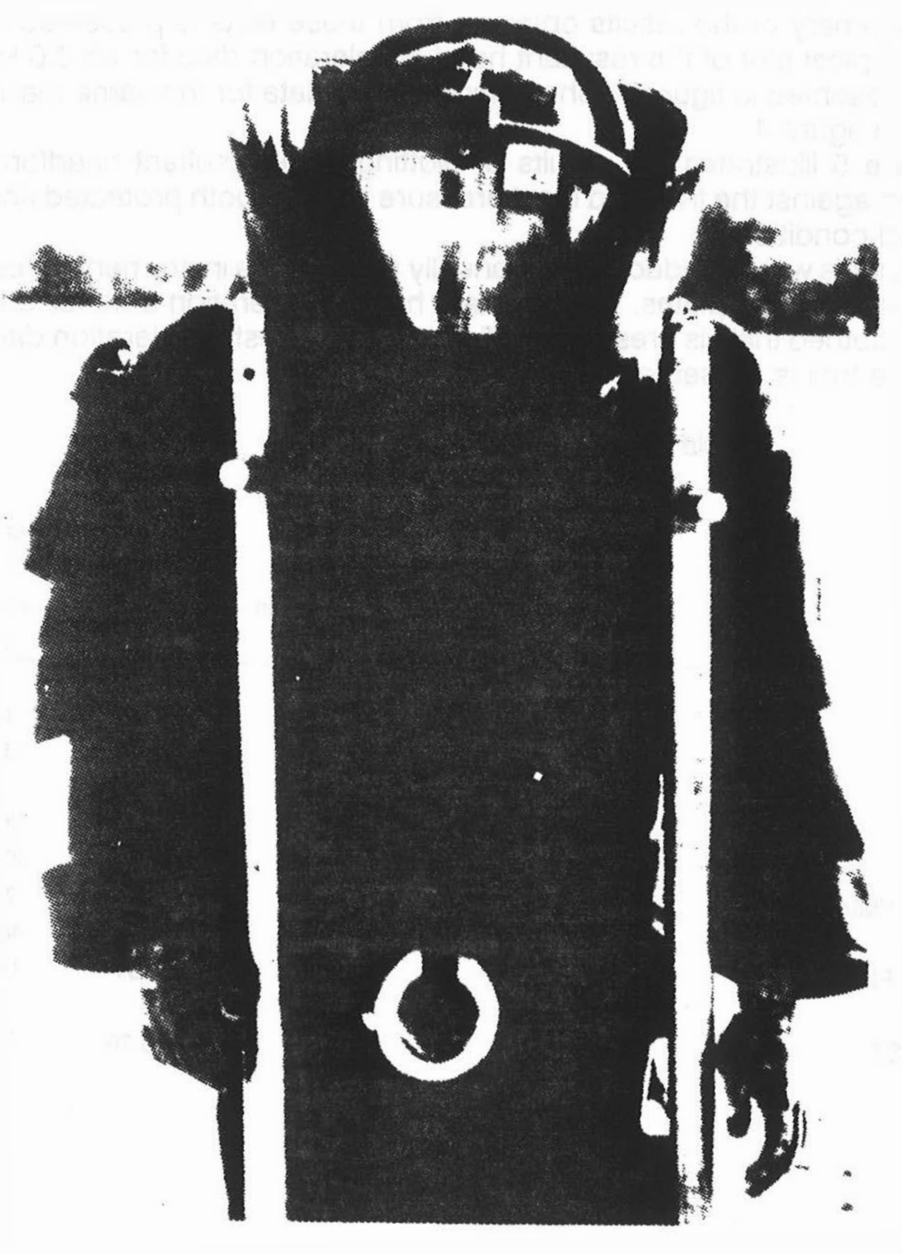

Figure 2: Experimental Test Dummy With Protective Suit.

RESULTS

The complete test program involved a series of 30 explosive test charges. A total of 23 of these tests was captured using the data acquisition system. Only lateral and anteroposterior chest accelerations were useful for analysis due to extreme noise artifacts in the superior-inferior chest acceleration data.

A summary of the results obtained from these tests is presented in Table 1. A typical plot of the resultant head acceleration data for an 8.0 kg charge is presented in figure 3. Chest acceleration data for the same trial is presented in figure 4.

Figure 5 illustrates the results of plotting peak resultant headform acceleration against the free field blast pressure data for both protected and unprotected conditions.

Two trials were conducted by manually pushing the instrumented test dummy onto the steel plates. The resultant head acceleration data for one of these unclothed trials is presented in figure 6. The chest acceleration data for the same trial is presented in figure 7.

Table 1: Summary of Test Results

Condition	Mass of Explosive (kg)	Mean Peak Pressure (kPa)	Mean Impulse (kPa-ms)	Mean Duration (ms)	Mean Peak Resultant Head Acc. (g)	Mean Peak Chest Lat. Acc. (g)	Mean Peak Chest A/P Acc. (g)
UNPROTECTED	2.00	164.80	81.00	1.34	166.00	3.21	41.44
(Without Protective Suit)	4.00	314.00	106.00	1.18	291.55	d.l.*	d.l.*
PROTECTED	2.00	154.30	74.67	1.16	16.25	2.00	15.54
(With Protective Suit)	4.00	273.14	89.71	1.02	34.14	27.46	31.88
Second Impact Into Steel Plate					65.44	7.85	9.52
	8.00	423.50	72.80	0.50	79.80	46.71	67.40
Second Impact Into Steel Plate					67.31	17.91	28.34
MANUAL PUSHOVER TEST (Without Protection)					386.20	7.99	27.30

* denotes data loss

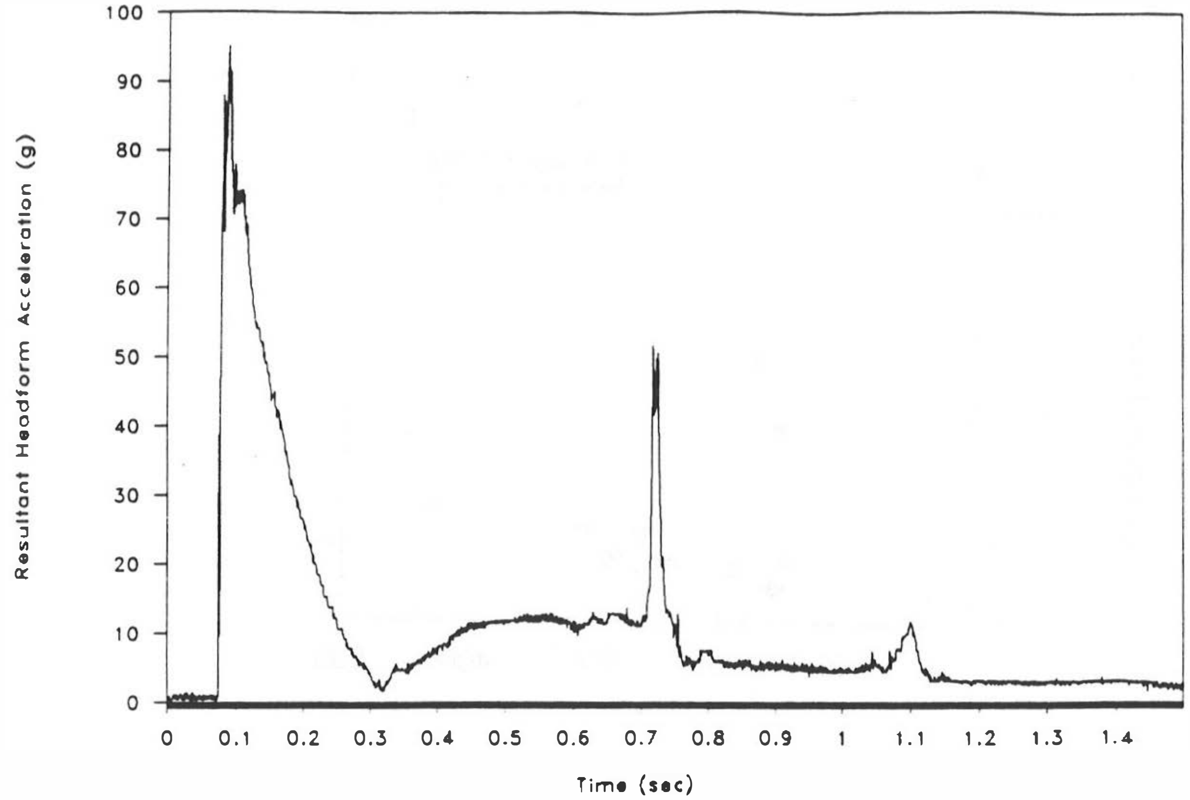

Figure 3: Resultant Head Acceleration Following 423 Kpa Blast Overpressure While Wearing Protective Suit.

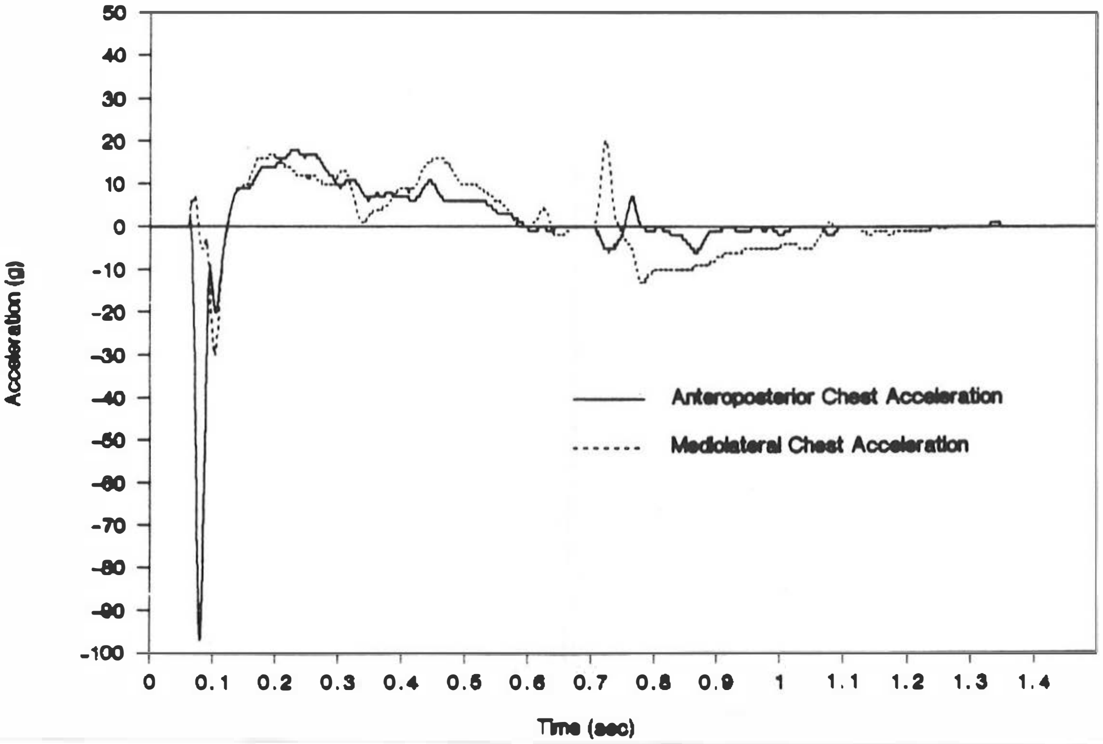

Figure 4: Chest Accelerations (Anteroposterior and Mediolateral) Following 423 Kpa Blast Overpressure While Wearing Protective Suit.

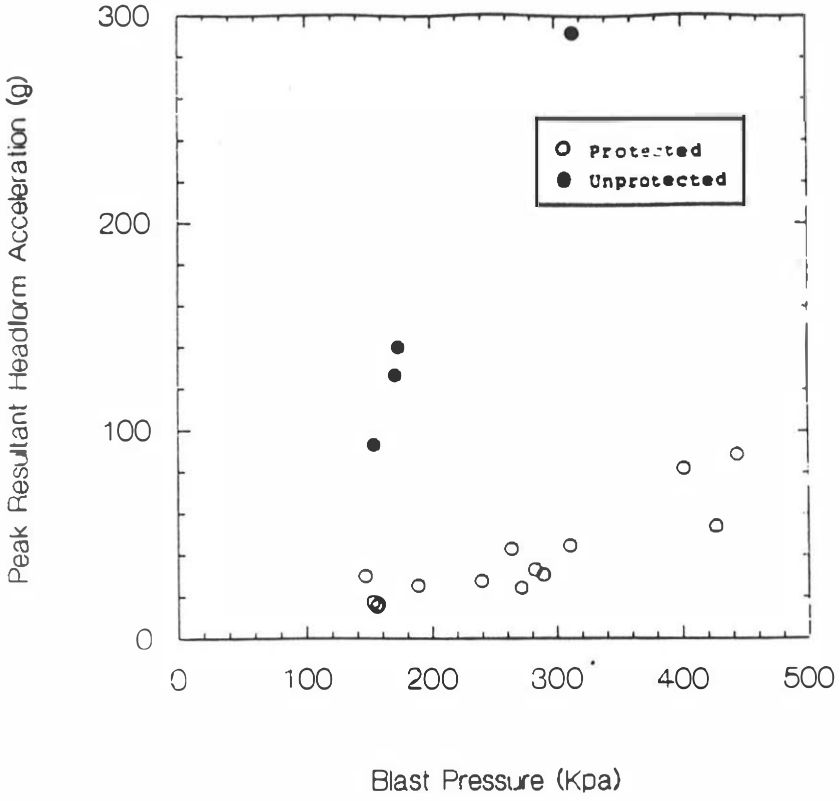

Figure 5: **Peak Resultant Head Accelerations Plotted Against Free Field Blast Pressure Data For Protected and Unprotected Conditions.**

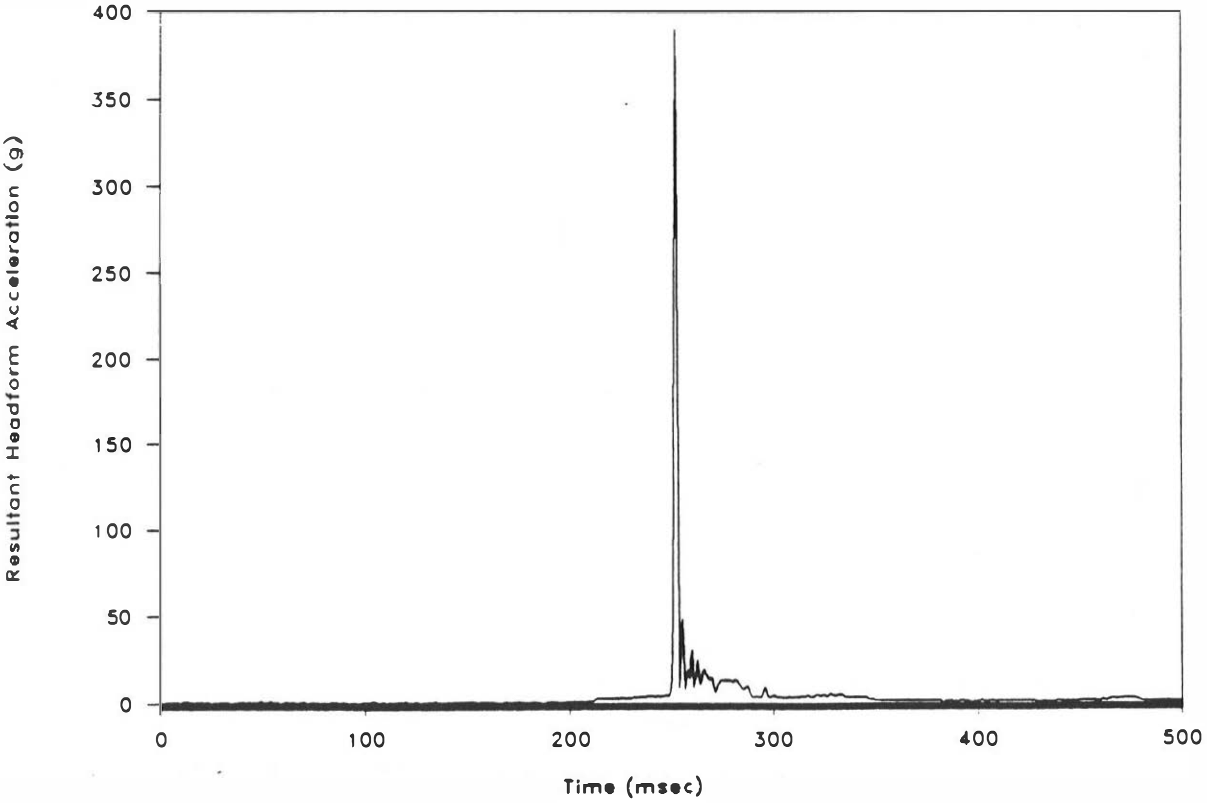

Figure 6: **Resultant Head Acceleration From Manual Pushover Testing Without Protective Clothing.**

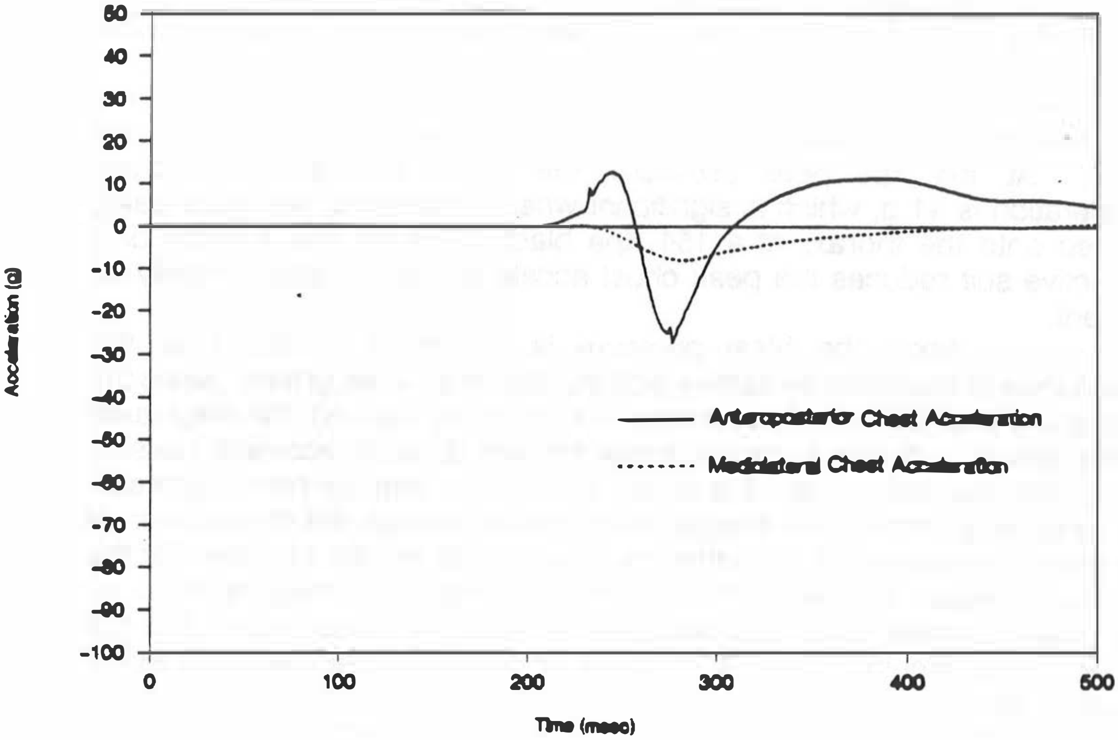

Figure 7: Chest Acceleration Data (Anteroposterior and Mediolateral) Following Manual Pushover Testing Without Protective Clothing.

DISCUSSION

The data presented above indicate that impact injury can be a significant danger when dealing with explosives devices. Those tests conducted on the test dummy without protection indicate that the initial blast wave pulse is significant enough to induce acceleration injury. A 314 Kpa pressure wave generates a blast acceleration pulse of 292 g to the head, well within the range of serious closed head injury. It is not difficult to speculate that the impact into the steel plate would likely be fatal.[2] The manual trials without protection would support this since these tests produced peak resultant head accelerations of 386 g. Similar impacts, caused by being blown back from a blast would likely produce similar head accelerations.

The addition of protective clothing provides a significant reduction in the blast acceleration pulse experienced by the head. At 154 kPa (2.0 kg charge mass), the peak resultant head acceleration was reduced from a

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[2] Impact against the steel plate also occurred during this trial; however, data was not captured by the a/d system.

mean of 166 g to below 20 g. This translates to approximately an 88 percent reduction in the peak headform acceleration when an adequate protective helmet was worn during the blast. A similar reduction was found for those trials conducted at 273 kPa.

As with the head accelerations, the chest accelerations which are generated during unprotected test situations may be associated with severe injury. At 164 Kpa peak pressure, the mean anteroposterior chest acceleration is 41 g, which is significant when considering the force being exerted onto the thorax. At a 154 Kpa blast pressure, the addition of a protective suit reduces the peak chest accelerations by approximately 63 percent.

When the blast pressure is increased to 423 Kpa, the importance of adequate protective clothing becomes even greater, since the lack of any protection likely coincides with mortality. As well, the magnitude of the blast is sufficient to rapidly throw the test dummy rearward, causing impact into the steel plates. It is during this impact, that the helmet protects the head by absorbing the energy of the impact through the deformation of the impact attenuating liner within the helmet. The results obtained for the 423 Kpa pressure tests illustrate that while wearing bomb disposal clothing, the peak resultant head accelerations for both the blast pulse and the impact pulse remain below 100 g. These levels of head acceleration would result in minor injury.

In conclusion, the test results show that for blast pressures in the range of 154 Kpa to 423 Kpa, injury due to impact can be fatal without the use of proper protective equipment. The use of an instrumented test dummy demonstrates that the bomb blast can generate two significant accelerations, firstly, as the body is accelerated back due to the blast itself and secondly, as the body strikes a solid unyielding surface (in this case the steel plates). As the data illustrates, the kinematic profile of the dominant axis shows that the head is subjected to an initial positive acceleration, quickly followed by a negative acceleration phase as the dummy strikes the steel plate. It is speculated that this rapid change in direction may have some additional implications regarding the mechanism of brain injury during bomb blast situations.

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