PERFORMANCE EVALUATION OF BALLISTIC HELMET TECHNOLOGIES

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Summary

Behind armour blunt trauma is an important and immediate concern for ballistic helmets especially since the introduction of lightweight composite materials that are more compliant under impact. Different ballistic helmet constructions were selected to evaluate the capability of current technologies to mitigate blunt trauma while stopping high-velocity projectiles. A series of tests was conducted with a novel headform designed to measure the dynamic load applied by the back face deformation of helmet during impact. Experimental results are presented and the effect of various parameters (e.g., helmet shell, stand-off, energy absorbing liner material) on the capability to reduce impact force is discussed.

1. Introduction

As lighter ballistic helmet shells are becoming available on the market, behind armour blunt trauma (BABT) effects are expected to be more difficult to overcome. In fact, because these helmets are lighter, they have less structural resistance, which often results in larger deformation under ballistic impact.

Until recently no test method was available to evaluate the injurious effects of ballistic helmet backface deformations. Current procedures [2, 3, 4, 5, 6] address penetration resistance but lack injury risk evaluation for non-penetrating ballistic impacts. Now, with the culmination of several years of research work [7, 8, 9, 10, 11, 1], a test method is available to evaluate the level of protection offered. This procedure uses an instrumented headform to measure the dynamic load applied to the head by the backface deformation. The risk of trauma is assessed by comparing the measurements (i.e. peak force of individual load cells) to the human injury tolerance threshold for skull fracture presented in Figure 1.

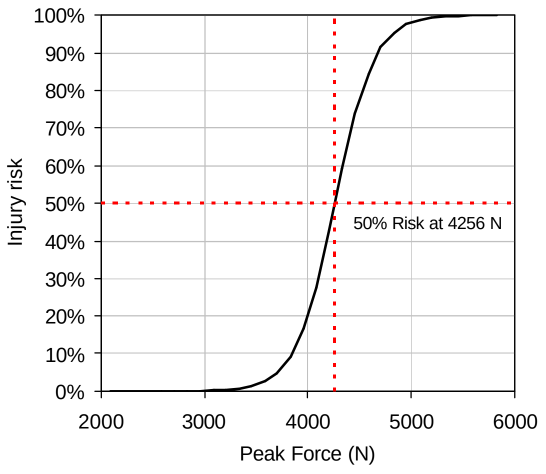


Figure 1. Skull fracture injury function [1].

With this method it is now possible to examine further key design characteristics of helmets for optimizing protection performance. The results of the test program presented here will provide preliminary results on the effects of the standoff distance, the impact liner material, and the stiffness of the helmet shell.

2. Materials and Methods

Helmet models used in this study were selected to represent current designs having a relatively stiff shell and new lightweight models. Details of test helmet samples are presented in Table 1. Helmets were tested as obtained from the manufacturers without any modification. For the current designs, two models were considered, i.e. with and without Energy Absorbing (EA) liner material. Two sizes (medium and large) of the lightweight model were obtained to study the effects of standoff on the measured force. It should be noted that the lightweight helmet model had comfort foam pads glued on the inside of the ballistic shell. The selected helmet models had similar ballistic penetration performance (V_{50}=630-670 m/s for 17 gr FSP) but were fabricated by different manufacturers.

Table 1. Test samples.

Test Sample	Description	Size	Standoff[1] (mm)	Helmet Weight[2] (kg)	Areal density[3] (kg/m^2)
A	Current design, no energy absorbing liner material	M	20.6	1.47	10.8
B	Current design with energy absorbing liner material	M	23.8	1.51	10.0
C	New lightweight model	M	20.6	1.10	6.5
D	New lightweight model	L	27.0	1.17	6.5

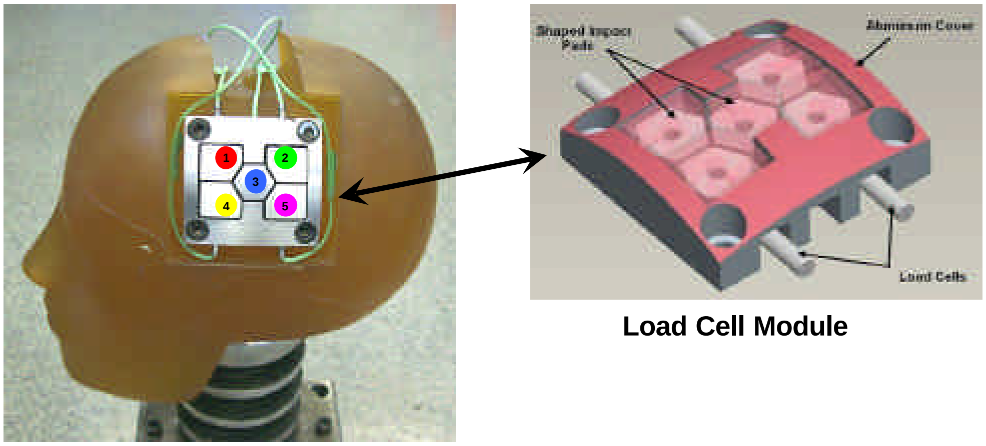
[1] distance measured between the inside of the helmet and the top of the headform's skin.

[2] total weight including the suspension system and energy absorbing material, if any.

[3] estimated value based on weight and coverage area.

The 9 x 19 mm FMJ Ball round (124 gr) was selected in this study because it has the potential of causing significant backface deformation without penetrating the armour. This ammunition is widely used throughout the world for military pistols and sub-machine guns. It is also defined in NIJ test Standard 0101.04 for body armour [12] to represent a typical handgun threat and can to some extent represent the effect of heavier fragment impacts.

The risk of blunt trauma was evaluated using the test method and the instrumented headform developed previously [13]. Five load cells (Kistler Type 9212) are mounted on a rigid module installed on a headform cast in urethane elastomer as shown in Figure 2. The module can be installed on either sides of the headform and allow for measurement of the dynamic force on the skull. A piece of synthetic skin recovers the entire module. The headform assembly is mounted on a flexible Hybrid III neck. A sheet of pressure sensitive film is placed directly over the top surface of the load cell module to verify impact location. Tests were conducted at different impact velocities up to 80% of the ballistic



Load Cell Module

Figure 2. Headform instrumented with load cell module (cover skin removed).

limit of each helmet model for the 9 mm FMJ bullet. The target was positioned at 5 m from the muzzle. Each helmet sample was tested twice, once each on left and right sides.

Initially, the headform position was adjusted to target the centre load cell using a laser bore sight to confirm alignment. A new sheet of pressure sensitive film was placed on the load cell module before putting the skin cover in place. After installing the helmet on the headform, it was levelled laterally and a positioning index gauge was used to adjust the helmet height at the brow. The retention system was then adjusted as required to securely fit the helmet. A target point on the exterior of the helmet was then marked using a laser bore sight. The headform position was readjusted such that the target point on the helmet is perpendicular to the line of flight. The helmet and skin cover were removed to verify that the target point was still aligned with the centre load cell. They were put back in place before the test. Figure 3 shows the typical setup with a test helmet installed on the ballistic headform.

Figure 3. Test setup.

The load cells were conditioned with charge amplifiers, Kistler Model 5011, set to the appropriate gains to maximize signal to noise ratio. Anti-aliasing filtering was performed (Frequency Devices Inc. Model D64L4B, low-pass 4-pole Butterworth, cutoff frequency 40 kHz) on the signals prior to analog-to-digital conversion. Data recording was conducted with data acquisition boards (National Instruments, Model PCI-6110) installed into a personal computer. The sampling frequency corresponded to 200 kHz. A 35.5 GHz Doppler radar (Model BR-3502, Infinition Inc.) was used to measure the velocity of the projectiles.

3. Results

Figure 4 shows the peak force of the five individual load cells as a function of the impact velocity while Figure 5 represents the trend between the peak value of the sum of the five load cell traces vs. the impact velocity. All peak impact forces measured were below the 50% risk of skull fracture threshold proposed previously [1]. In general, the pressure sensitive films indicated that the backface loading was centred on the load cell module as shown in Figure 6 where the darker area corresponds to regions of higher pressure.

The relationship between projectile velocity and impact force is different for each helmet model and size. Higher peak force values were measured with helmet model A and C suggesting that similar level of protection can be offered against non-penetrating impacts for current technologies without EA materials and new lightweight helmets.

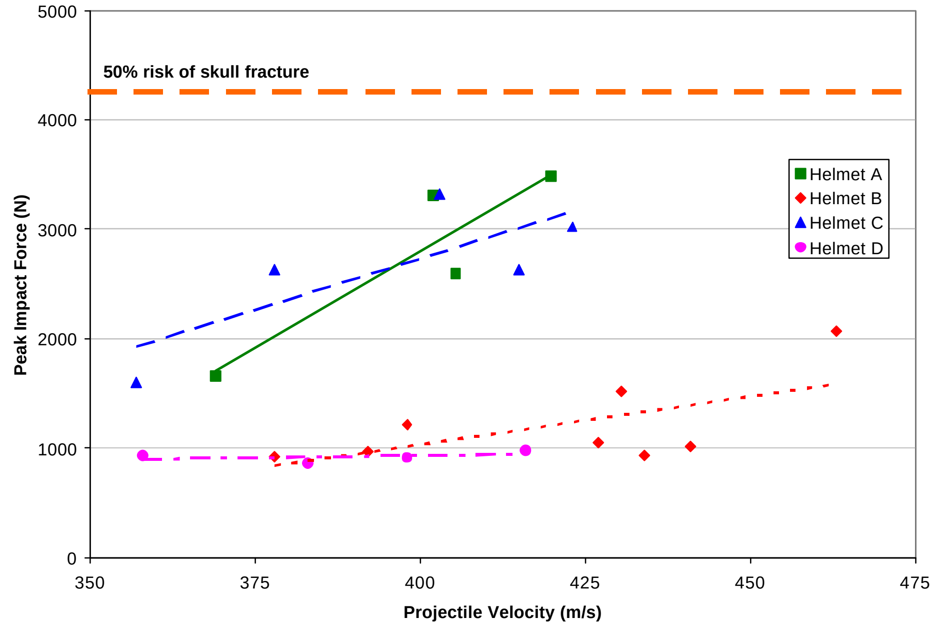


Figure 4. Peak impact force of individual load cells as a function of projectile velocity.

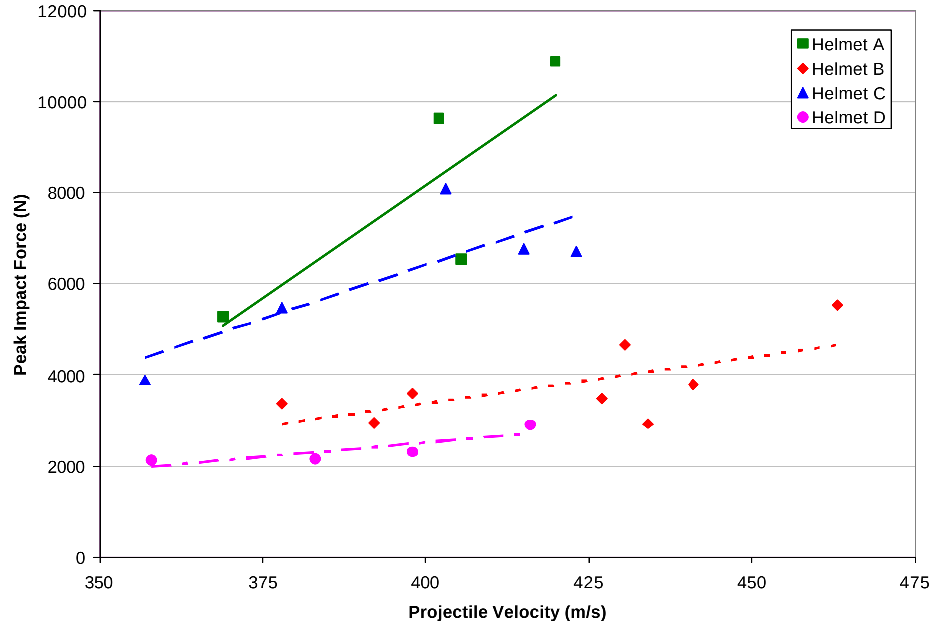


Figure 5. Peak of the sum of impact force as a function of the projectile velocity.

A significant reduction in the peak force value was observed between helmet models A and B, i.e. helmets of comparable weight but with or without EA liner material. A comparison of the dynamic response and pressure sensitive films show that EA material reduces the peak forces most likely by distributing the impact reactions over a larger area and longer period of time (Figure 7 and Figure 8). The location of the load cells on the headform is shown in Figure 2.

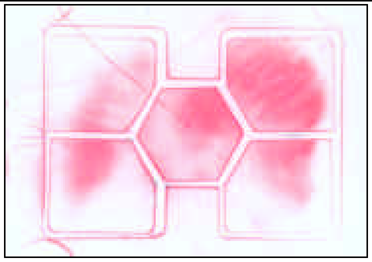


Figure 6. Typical result obtained with pressure sensitive film.

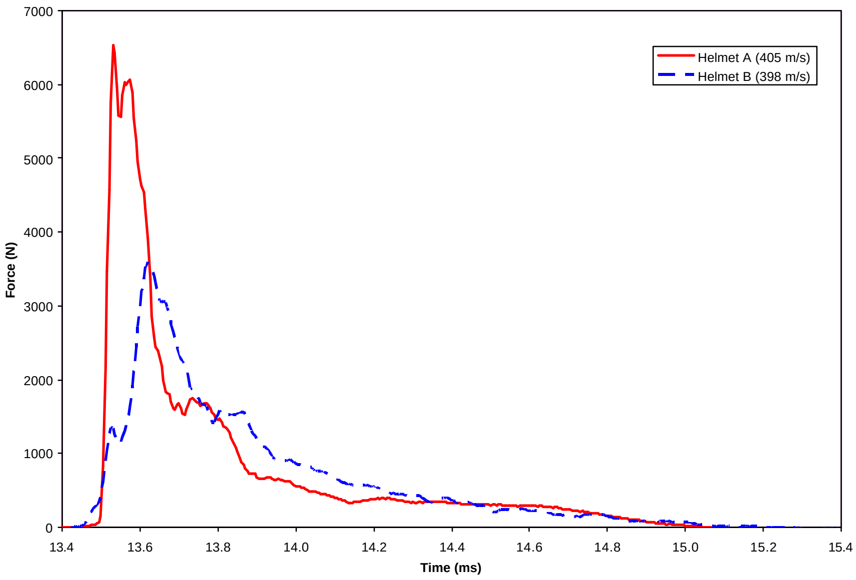


Figure 7. Sum of impact force measurement for helmet model A and B.

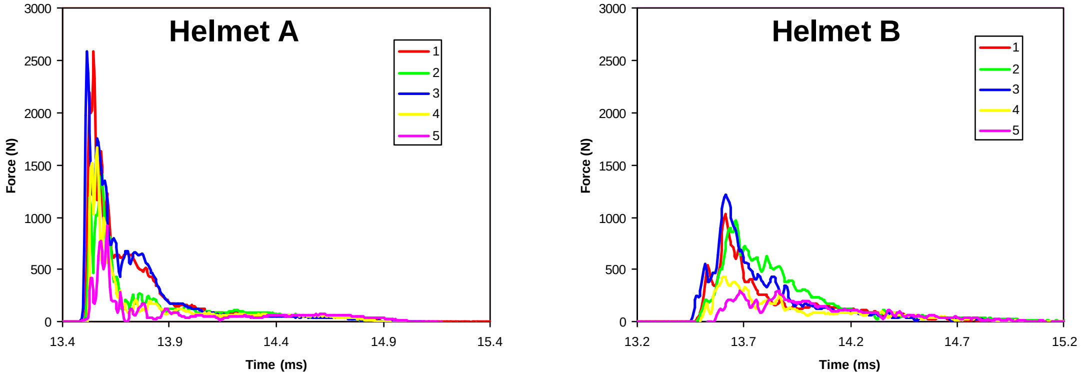


Figure 8. Individual load cell measurement for helmet model A (405 m/s) and model B (398 m/s).

Another significant reduction of the peak force is observed from the medium to large size for the lightweight helmet model C and D. For the large size, an impact velocity increase has a limited effect on the peak force measured as shown in Figure 4 and Figure 5. The additional offset between the helmet backface and the headform appears to delay the onset of loading and the force magnitude (Figure 9). Interestingly, peak values measured with helmet model B (current design with EA material, medium size) and helmet model D (lightweight, large size) were similar.

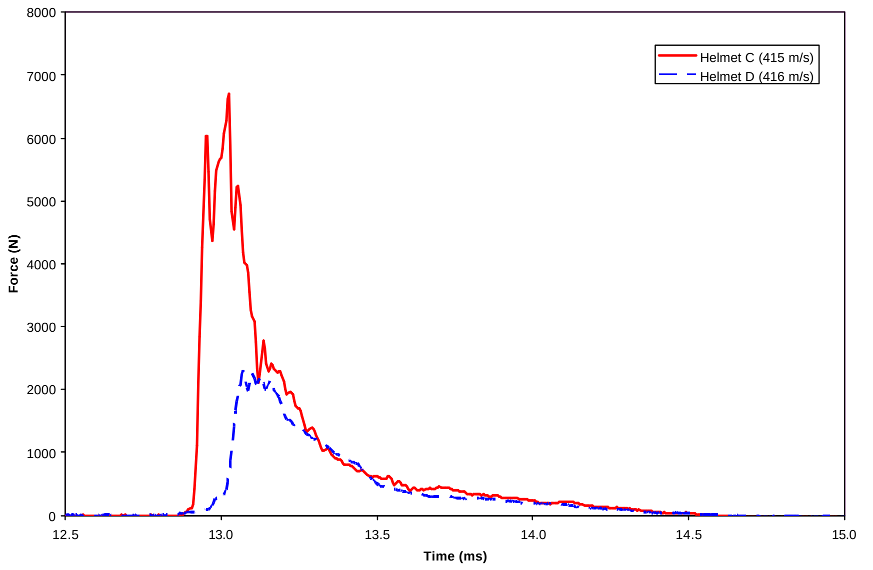


Figure 9. Sum of impact force measurement for helmet model C and D.

4. Conclusions

Using the peak impact force of individual load cells, the results indicated that lightweight helmet design provide a similar level of protection against blunt trauma to existing technologies (helmet A vs. helmet C). However, when considering the sum of impact force, helmet A offered the worst performance. Significant load reduction can be achieved either by increasing the standoff (medium vs. large) or by adding energy absorbing liner material to distribute the force over a greater area. These results provide general guidelines in terms of what should be considered for better ballistic helmet designs. Additional testing should be conducted to look in more detail at the effects of these parameters. For a given shell construction, which EA material provides better impact reduction? What are the effects of hot and cold temperature vs. ambient conditions? Which is the optimal standoff distance? Obviously, these aspects are also dependant on the threat selected.

The current test program also showed some deficiencies in the current test procedure. Trials observations showed that helmet backface deformation is often greater than the sensing area which indicates that it may be possible to not record the real peak load. As a result, the load cell module shown in Figure 2 is being redesigned to overcome this deficiency. The new load cell configuration proposed is illustrated in Figure 10. The size of individual impact pads is similar to the previous version but two additional load cells are being added. Currently, impact locations are limited to left and right sides. Additional capabilities are being considered to include front and rear target zones as shown in Figure 11.

It is also expected that other projectiles or helmets having a relatively stiff shell will not produce significant backface deformation and thus, lower impact loads. While this implies that the risk of skull fracture is low, there is the potential that the impact energy transfer to the head may be sufficient to induce brain injuries. Therefore, in refining the design of the ballistic headform, considerations were taken to include accelerometers at the centre of gravity to obtain another measurement that can be used to assess the loading severity. Finally, the standardized ISO headform shape was selected for the new design since its anthropometry is recognized worldwide and it is available in many sizes [14].

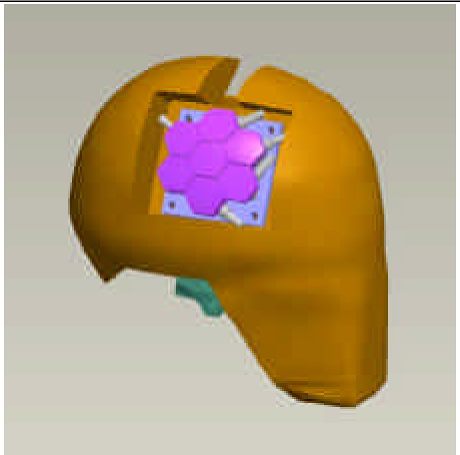


Figure 10. New load cell module configuration.

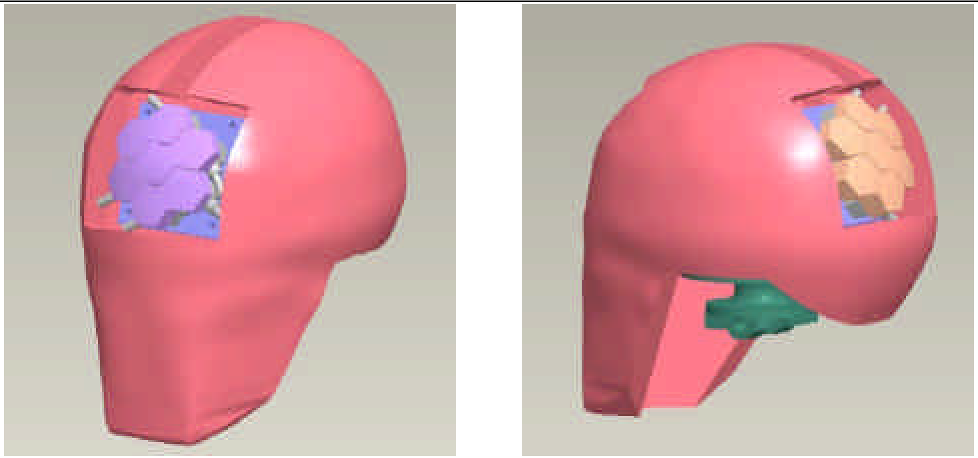


Figure 11. Front-rear headform design.

5. Acknowledgement

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