# Shell Plate Method of Reconstructing Behind Armour Blunt Trauma Impact Scenarios for Soft Armour Using a Detailed Thorax Model

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## I. INTRODUCTION

Behind Armour Blunt Trauma (BABT), comprising soft tissue damage and hard tissue fracture may occur in the thorax due to the dynamic deformation of protective body armour resulting from a non-perforating projectile impact. Several experimental studies have been undertaken to investigate BABT injury, with early tests on live goats protected by flexible (soft) body armour [1] and tests of armour with clay backing [2], which led to the 44 mm maximum back-face deformation (BFD) criterion. The use of clay evolved into standard methodologies that assess the potential for BABT injury and evaluate soft armour [3]. Ballistic gelatin is an alternative to clay that demonstrates comparable BFD [2], but the greater cost and the need for high-speed video to track the BFD led clay to become the economical method of choice.

Due to the high velocity and short duration of the armour and torso interaction in BABT, existing thorax injury criteria, such as those used in the automotive industry, are limited in their application when considering BABT. A previous study by the authors investigated BABT scenarios from a database of survivors [4] by recreating the impact event using a detailed human body thorax Finite Element (FE) model (Fig. 1(a)) and a Rigid Sphere (RS) impactor [5]. Overall, the FE model and the RS impactor demonstrated good agreement with the reported injuries from the database, demonstrating the ability to reconstruct real-world BABT cases using experimental data to define the boundary conditions and a thorax FE model to assess the potential for injury. However, the previous study [5] simplified impact conditions by using an RS that was limited by its constant shape. The aim of the current study is to improve BABT loading on the thorax model by simulating the soft armour BFD as observed in experimental gelatin tests.

## II. METHODS

A method for modelling BABT impact conditions, known as the Loader Plate (LP) method, was developed to more accurately represent the actual armour BFD history. The LP utilised a deformable circular shell mesh (120 mm diameter, 3–16 mm elements) having nodes with individual prescribed displacement histories to re-create the experimentally measured armour BFD. As a first assessment, the LP was defined to recreate the RS impact scenario and demonstrated good correspondence for a 30 mm radius RS impactor applied to the FE thorax at a velocity of 30 m/s (Fig. 1(a)).

Experimental tests on soft armour backed by a gelatin block (10% ballistic gelatin at 4°C) were performed using impact conditions from the survivors database [4]. The armour BFD was captured with high-speed imaging (35,000 fps), tracked, digitised and then a surface was generated by revolving the digitised history about the axis centred at the peak back-face displacement. Three impact cases (id# 3066, 2576 and 990) from the survivors database (Table I), which was previously investigated using the RS method [5], were applied to the FE thorax model using the LP with their corresponding surface histories measured from the gelatin tests. An assumption was made that the armour and gelatin interaction was comparable to that of the armour and thorax.

## III. INITIAL FINDINGS

The LP recreation of the 30 mm radius RS impactor applied to the FE thorax at 30 m/s yielded reasonable agreement for the contact forces between the thorax muscle, ribcage, sternum and lungs (Fig. 1(b)), demonstrating the efficacy of the LP with similar computational time to the RS. The LP recreations of the three BABT impact cases also predicted the reported injuries [6]. When comparing the FE model predictions, both the

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RS and the LP yielded the same number of rib fractures; however, the LP methodology yielded greater pulmonary contusion, impulse and contact energy (Table I).

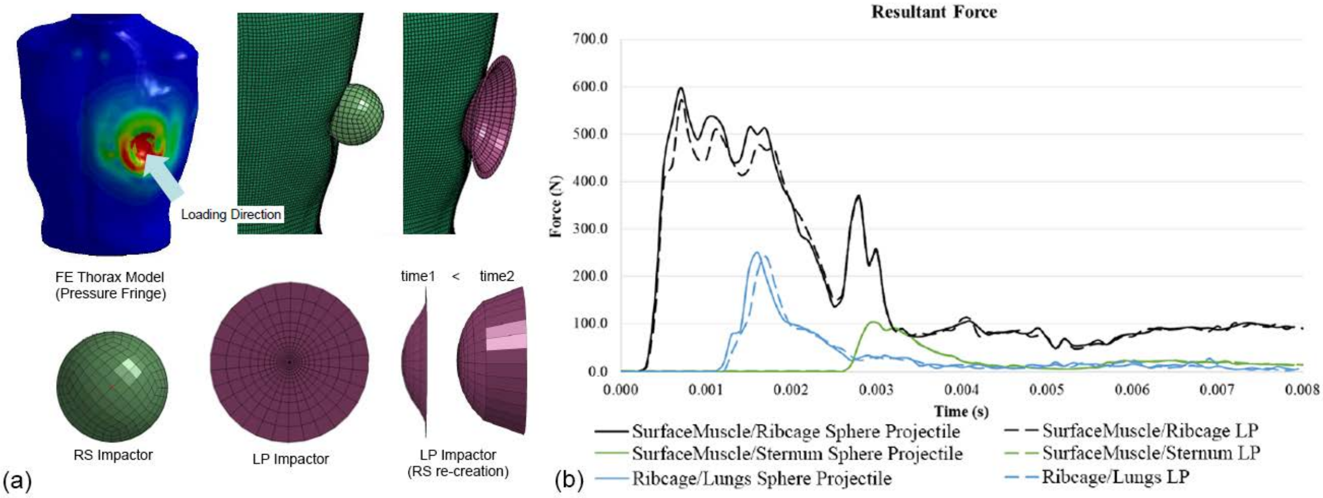

Fig. 1. (a) 30 m/s impact applied at an oblique angle on the FE thorax and the RS and LP mesh; (b) 30 m/s impact resultant contact force responses for control case (equivalent RS and LP boundary condition).

TABLE I

BABT IMPACT CASES FOR RECONSTRUCTION AND FE MODEL PREDICTIONS

| BABT Survivor Cases | | | RS Impactor [5] | | | LP Impactor | | |
|---|---|---|---|---|---|---|---|---|
| Case | Injury Rank # [4] | Reported injury [6] | Rib Fracture and Pulmonary Contusion (%) | Impulse (kN-ms) | Contact Energy (J) | Rib Fracture and Pulmonary Contusion (%) | Impulse (kN-ms) | Contact Energy (J) |
| 3066 | 1 (minor) | Skin abrasion | No and 0.5% left lung volume | 0.91 | 15 | No and 1.1% left lung volume | 1.72 | 50 |
| 2576 | 2 (moderate) | Fracture, 8th rib | Yes and 0.9% left lung volume | 4.84 | 49 | Yes and 1.4% left lung volume | 6.24 | 104 |
| 990 | 3 (severe) | Fracture, 9th rib, lung contusion | Yes and 3.7% left lung volume | 4.24 | 128 | Yes and 7.7% left lung volume | 7.26 | 311 |

## IV. DISCUSSION

Only minor differences were identified between the RS and the LP in the control case (30 mm diameter, 30 m/s) and were attributed to the small mesh differences between the RS and the LP (Fig. 1(a)). The automatically generated mesh pattern of the RS was optimised for its spherical shape, whereas the mesh pattern of the LP allowed for the recreation of asymmetric surfaces and evolving shape and curvature over time. Considering the recreation cases, the larger impact area of the LP, corresponding to the experiments, explained the differences in the pulmonary contusion, impulse and contact energy. Consequently, the magnitudes of the pressure waves that propagated into the lungs also increased. The similar predictions of rib fractures for the RS and LP impactors were expected because they had equal peak BFDs and the hard tissue failure in the FE thorax model was related to the BFD [7]. The current study demonstrated the efficacy of the LP impactor to accurately recreate BABT loading on the thorax by simulating the change in shape over time of the BFD observed in experimental tests of soft armour with ballistic gelatin backing. Ultimately, this method provides improvements to the boundary conditions for BABT loading and therefore for assessing the potential for injury risk from BABT.

## V. REFERENCES

[1] Goldfarb M.A., *et al*., Aberdeen Proving Ground, 1975. [2] Prather R.N., *et al*., Aberdeen Proving Ground, 1977. [3] Hanlon E., *et al*., *Military Med*, 2012. [4] Bir C., *et al*., International Ballistics Symposium, 2017. [5] Cronin D.S., IRCOBI, 2018. [6] Cronin D.S., IRCOBI, 2012. [7] Forbes P.A., *et al*., *Int J Crashworthiness*, 2006.